UNIVERSITI TEKNOLOGI PETRONAS

SIMULATION STUDY ON OIL SWELLING DURING CO2 INJECTION FOR LIGHT OIL SAMPLES

By

MIHRAB MUTWAKIL MOHAMED ABDU

12930

Dissertation submitted in partial fulfilment of
The requirements for the
Bachelor of Engineering (Hons)
(PETROLEUM ENGINEERING AND GEOSCIENCE)

JANUARY 2012

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by, ______________________

(Mr. ALI F. MANGI ALTA'EE)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JANUARY 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible of the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MIHRAB MUTWAKIL MOHAMED ABDU

ABSTRACT

Carbon dioxide CO_2 injection method is one of enhanced oil recovery EOR techniques that is taking the place of interest in oil industry nowadays because of its availability and low cost relatively. Oil swelling during the process of miscible CO_2 flooding is the main factor influencing the effectiveness of this method to enhance oil recovery, since it will improve the permeability of the rock when CO_2 extracts the residual oil and swells it to let it move leaving more connected pore spaces in the reservoir. The main objective of this study is to determine the swelling factor of some light oil samples having different compositions and properties, and analyse the result to predict factors that affect oil swelling factor so as to technically evaluate the injection process since CO_2 injection technique has been widely used in oil industry. CO_2 injection evaluation comprises two categories; technical and economical. Technical factor is based on geological, geophysical, engineering and transportation issues. The considered issue in this study is one of the engineering issues which is the effect of CO_2 injection on hydrocarbon fluid volume.

Oil swelling factor due to CO_2 flooding was determined by simulating some lab data using CMG software. A dead oil sample was recombined with methane and CO_2 gas after its composition has been identified by gas chromatography analysis. The composition of the other samples has been taken from an SPE paper prepared by Nancy, Italic (1990). Oil samples compositions were entered to the CMG software. Swelling test was run to determine the swelling factor; it was applied for different CO_2 concentrations starting from 20% mole, 40% mole, 50% mole, & 60% mole. Constant composition test CCE was run to predict the saturation pressure at each CO_2 concentration. The result and output of this simulation were analysed, & graphs have been created for the completion of this project. During this project it was verified that, Based on the technical/ oil swelling factors, CO_2 flooding is considered as feasible process up to 60% mole for all oil samples, since the swelling factors did not reach the critical point, beyond which the swelling factor start to decrease.

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CHAPTER 1

INTRODUCTION

1.1 Background Study:

During the life of an oil reservoir, production is usually carried out by primary recovery, secondary recovery, and lastly tertiary recovery, or enhanced oil recovery (EOR).

In general, EOR is any techniques have been taken to proceed in order to enhance oil recovery after it has been water flooded. EOR is divided into two techniques; thermal and non-thermal methods, this classification are based on whether heat is involved in some form. Thermal methods mainly consist of steam injection (hot water steam) while non-thermal EOR methods consist of chemical and miscible processes. Chemical methods such as polymer and emulsions floods and miscible methods include high pressure miscible drives using hydrocarbon gas, nitrogen N_2, or carbon dioxide CO_2. The selection of EOR methods basically based on the well needs, reservoir type and situation, as well as economical factors (Farouq & Thomas, 1989).

Carbon dioxide flooding is one of the most effective methods of EOR techniques; it is commonly used due to the following reasons:

- It is available and can be easily obtained.
- It has low cost relatively.
- It has high displacement efficiency due to its solubility and miscibility in oil.
- It has low minimum miscibility pressure MMP.
- It can be used in two ways; miscible and immiscible process.
- It is applicable to wide range of reservoirs and it improves formation permeability, (Yongmao, Italic, 2004).

As carbon dioxide has been injected to a particular reservoir at a specific depth "depending on water contact depth", CO_2 gas molecules start to dissolve in oil phase "mainly light and moderate oil" changing its physical properties; such as density, viscosity, solubility and volume while leaving the chemical properties the same "CO_2 gas is compatible with oil phase" (Enayati, Italic., 2008). This project focuses only on one of the most important effects of CO_2 while injection process which is the hydrocarbon volume change or oil swelling factor of light oil samples.

1.2 Problem Statement:

- CO_2 injection technique has been widely used in oil industry, that's why intensive studies should be made in order to identify the effects of this technique on crude oil as well as on the reservoir rock, and to evaluate the injection process.
- Oil swelling factor is the theory behind CO_2 flooding. Thusly, it should be determined so as to control oil mobility & oil production.

1.3 Objectives & Scope of Study:

1.3.1 Objectives:

- Determine oil swelling factor during CO_2 flooding for different oil samples using CMG software.
- Estimate the relationship between injected CO_2 volume and oil swelling factor for EOR technical evaluation.

1.3.2 Scope of Study:

This project aims to technically analyse the swelling factor of light oil samples under study. CMG software was used to determine oil swelling factor, and analysis were made to estimate the optimum CO_2 range to be injected.

1.4 Project Feasibility:

This project is considered as feasible since all needed facilities such as laboratory equipments and CMG software are available at the place of study “Universiti Teknologi Petronas, UTP”, and the given time in order to complete the project is fairly suitable since the study would be on five oil samples.

CHAPTER 2

LITERATURE REVIEW

This chapter contains a brief review on CO_2 injection & its methods, oil swelling, finally some experimental studies.

2.1 Previous Studies on Carbon Dioxide Injection

During the fifties of the twentieth century, researchers started to look at the CO_2 EOR flooding process and its effect to reservoir characteristics (especially porosity and permeability) in the laboratory. Over time CO_2 flooding has become the leading enhanced oil recovery technique for light and medium oils. CO_2 miscible flooding improves oil recovery through gas drive, swelling of the oil and decreasing its viscosity. Currently, there are more than hundred CO_2 flooding projects operating in the world, most of them situated in the USA (Oskui and Jumaa, 2009).

2.2 Carbon dioxide flooding:

The use of CO_2 as a method of enhanced oil recovery has been studied since the early 1930 and it has been widely and significantly used in the 1970s and 1980s (Yongmao, Italic, 2004). When reservoir fluid (hydrocarbon and water) contains a significant amount of dissolved CO_2, its physical properties such as density, viscosity, compressibility and solubility are modified in a way that helps in recovering more oil.

Thus, CO_2 flooding should be used if CO_2 gas is available in adequate amounts and economically priced (Mungan, 1979).

It has been found that, CO_2 flooding is more effective in light to medium oil reservoirs, since CO_2 gas tends to extract lighter oil components first (C1 to C4), then with larger amount of CO_2, heavier components of hydrocarbon oil (C5, C6, and C7+) will be extracted, (Tsau, Italic., 2010).

Basically, there are two different ways of CO_2 injection; miscible and immiscible CO_2 displacement. The miscible CO_2 displacement is the process in which CO_2 gas will be injected to the reservoir under high pressure (above the minimum miscibility pressure MMP), and then CO_2 will liquefy and mix with oil phase forming a single-phase flow under reservoir condition. This method is used for light and medium oil reservoirs (David Martin, and Taber, 1992). While the immiscible CO_2 displacement is the process at which CO_2 gas will be injected to the reservoir under lower pressure relatively (below MMP), then some of CO_2 molecules will dissolve in oil phase reducing its viscosity, and the other some will push oil phase toward the producer well forming two-phase flow under reservoir condition.

Menzie and Nielson, (1963), and Holm and Josendal, (1974) have determined the efficiency and the effectiveness of carbon dioxide injection verifying that, CO_2 is an attractive gas for both miscible and immiscible processes. Furthermore, Zahidah, Italic (2011) have evaluated CO_2 gas injection as effective process through phase behaviour studies, vaporization test, and displacement test.

One of the most important properties of CO_2 that makes it favourable in EOR techniques is that, its ability to extract hydrocarbons from crude oil due to its high solubility during immiscible process, (Zahidah, Italic., 2001). Mungan, (1979) had mentioned that, the main advantage of immiscible CO2 injection is that, it is resulting in oil swelling and viscosity reduction although miscible CO_2 displacement is preferred to the immiscible process due to its higher displacement efficiency (Mungan, 1979).

On the other hand, Yongmao, Italic, (2004) said that, the miscible process is more recommended than immiscible displacement due to the high interfacial tension, high displacement efficiency, and as well as higher swelling factor in the miscible process (Yongmao, Italic., 2004). Gas molecular diffusion is involved in miscible carbon dioxide flood, so once CO_2 diffuses into oil phase, oil swelling will be resulting and that is considered to be the controlling mechanism in this process, (Edward and Joseph, 1974).

Injection of CO_2 in an oil reservoir will result in several mechanisms that will improve oil recovery which are: swelling of crude oil, viscosity reduction of crude oil, and oil vaporization by CO_2, (Klins, 1984; Ghalambor, 1990).

CO_2 injection evaluation comprises two categories; technical and economical. Technical factor is based on geological, geophysical, engineering, and transportation issues. The considered issue in this study is one of the engineering issues which is the effect of CO_2 injection on hydrocarbon composition and properties. Engineering issues concern with reservoir rock and hydrocarbon fluid parameters relevant to CO2 flooding (Bon and Sarma, 2004).

Evaluating reservoir rock is based on permeability which is by its role affected by Asphaltene precipitation during injection process. While evaluating hydrocarbon fluid is based on density and viscosity reduction, phase behavior change, and oil swelling (Bon and Sarma, 2004).

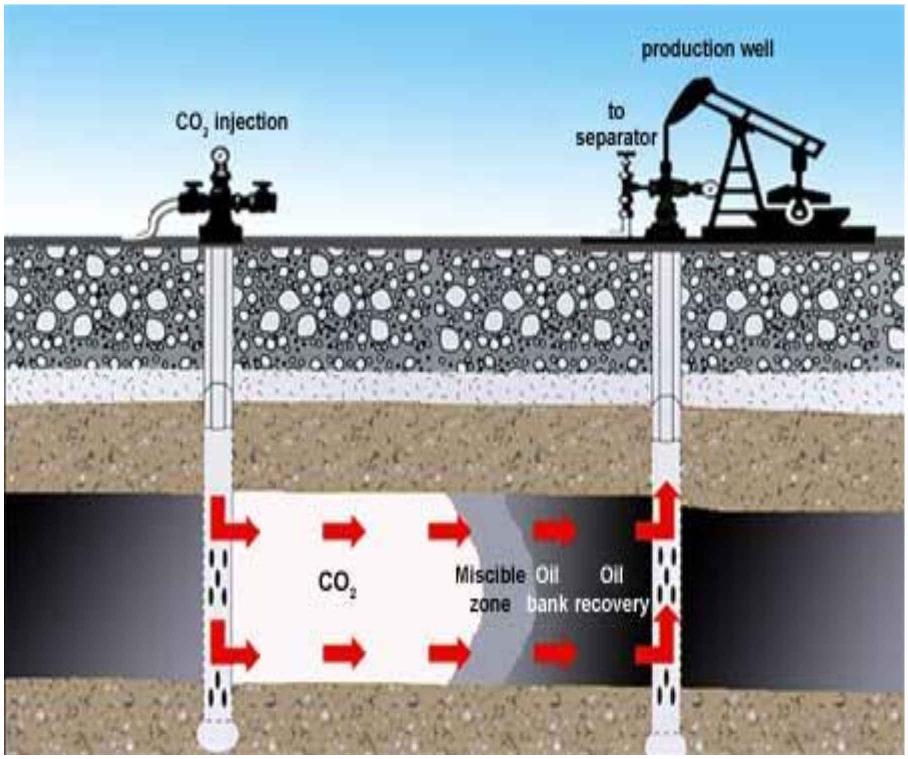


Figure -1: Carbon dioxide injection

2.3 Oil Swelling:

Carbon dioxide is soluble and miscible in crude oil, the thing that makes it to have high displacement efficiency. The solubility will aid to oil swelling as CO_2 concentration and pressure are increasing, (Miller and Jones, 1981; Ghalambor, 1990).

When CO_2 gas is injected to light or medium oil reservoir, the gas phase will start to dissolve in the liquid phase at the first or multi contact depending on reservoir pressure and oil properties. Thusly, oil volume increases because of two major reasons. The first reason is that, the dissolved gas will give an additional volume (the volume of gas molecules itself) to the mixture. The second reason is the oil molecules itself will expand and be larger in size when contacting with CO_2. This increment in oil volume will improve the mobility of the mixture so as to give a chance to reduce water production relatively (Yongmao, Italic., 2004; Mungan, 1979; David Martin, and Taber, 1992).

In a review and evaluation study on carbon dioxide flooding, Mungan found that Up to 700 SCF approximately of CO_2 will dissolve in one barrel of oil resulting in 10 % up to 40% increase in the volume of oil that can be recovered, this percentage is actually based on pressure, temperature, and composition of the crude oil at reservoir condition (Mungan, 1979). In other research, Enayati, Italic have stated that, not more than 25% of oil in place can be recovered using carbon dioxide flooding (Yongamoa, Italic., 2004; Enayati, Italic., 2008), while Mathiassen, (2003) stated that, enhancing oil recovery using CO_2 as injection gas will result in additional oil volume up to 15% of the oil initially in place. These percentages are totally dependent on oil swelling factor.

Oil swelling factor is defined as the ratio of the volume of the oil- CO_2 mixture to the initial volume of gas free oil at standard pressure and temperature (Ghedan, 2009). It is the main mechanism that is responsible for recovering the residual oil saturation in this process (Edward and Joseph, 1974). The importance of this ratio is also extended to determine how much CO_2 volume to be injected in order to recover the oil of a particular reservoir economically. The relationship between injected CO_2 and oil swelling factor is proportional up to the critical point which the increment or the swelling of oil beyond that point is no more economic.

Figure -2: Oil swelling

2.4 Experimental studies:

There were many different experiments have been conducted in order to evaluate and investigate miscible carbon dioxide flooding, oil recovery and oil swelling determination. These experiments vary due to the purpose of study.

Slim tube test is a kind of PVT analysis which is conducted in order to determine minimum miscibility pressure (Javadpour, Italic., 1998), (Strivastava, Italic., 2000), (Yongmao, Italic., 2004), and (Enayati, Italic., 2008). Moreover, it has been found that slim tube test can give immediate information regarding carbon dioxide injection operating pressure, but it has no indication on how efficient is the CO_2 flooding process, (Orr, Italic., 1982; Danesh, 1998; Ghedan, 2009).

Core displacement test is to determine MMP as well as recovery factor calculations (Yelling and Metcalfe, 1980; Zahidah, Italic., 2001).

CO_2 core floods experiment is to understand the displacement mechanisms of the injection process, and to determine the oil residual saturation in the swept zone as well as to know core permeability modification by CO_2 injection process, (Ghedan, 2009).

Swelling/extraction test is performed on dead oil samples in order to identify the phase behaviour of oil samples, determine reservoir fluid volume change (oil swelling) and composition change due to CO_2 injection, (Orr, Italic., 1981; Harmon, Italic., 1988; Hand, Italic., 1990; Ghalambor, Italic., 1990; Tsau, Italic., 2010).

Vapour/liquid equilibrium (VLE) test is a high pressure volumetric PVT test performed on recombined light oil samples to detect the physical behaviour of oil- CO_2 mixture (mainly oil swelling by CO_2). Its result are accurate in near well bore condition since the detected vapour bubbles will be extracted out of the PVT cell during the experiment, (Simon, Italic., 1978; Graue and Zana, 1981; Ghedan, 2009).

Constant composition expansion (CCE) test is similar to VLE test. It provides the relationship between bubble point pressure and injected CO2 volume as well as oil swelling factor determination. The only difference between VLE and CCE is that CCE results are accurate in reservoir condition since the detected vapour bubble of the mixture during pressure depletion will be kept inside PVT cell, (Zahidah, Italic., 2001).

The considered experiments during this simulation study are swelling test and constant composition expansion CCE test. Swelling test has been chosen because the aim of this research is to determine the oil swelling factor at reservoir conditions. CCE test was chosen to predict saturation pressure at different CO_2 concentrations. (Dong, Italic., 2000; Yongmao, Italic., 2004; Enayati, Italic., 2008).

2.5 Simulation Studies:

2.5.1 CMG Software:

CMG (Computer Modelling Group Ltd); it is a computer software of engineering and consulting firm company which is linked to the development of reservoir simulation software. Its focus is mainly on the development of the most common reservoir simulation technologies. It also helps oil industry to be more confident while using simulation technology in decision making during reservoir and production studies.

CMG provides reservoir simulation software for many different applications such as; conventional black oil extraction applications, complex phase behaviour, compositional and thermal applications. Its main goal is to develop a dynamic system which is capable of optimizing reservoir recovery and modelling reservoir and production systems.

CMG's reservoir simulators can be used to model complex reservoirs, well operating conditions and reservoir drive mechanisms. These simulators can also model more enhanced recovery methods including CO2 flooding. CMG also provides unique solutions for the most advanced complex recovery process situations for advanced recovery processes means, such as; steam floods, foamy oil, WAG, and gas restoration (http://www.cmgroup.com/company/aboutcmg.htm).

This software has different windows for different functions and applications, WinProp widow was used in order to run swelling test and CCE test.

2.5.2 WinProp:

WinProp is one of CMG Windows that is responsible of modeling the phase behavior and properties of reservoir fluids. It is a widespread equation of state engineering tool, determines the reservoir characteristics and compositional variations of reservoir fluids under simulation study. It can be used under different conditions either reservoir or surface conditions, whether laboratory projects, thermal composition, or compositional simulation.

Applications of WinProp:

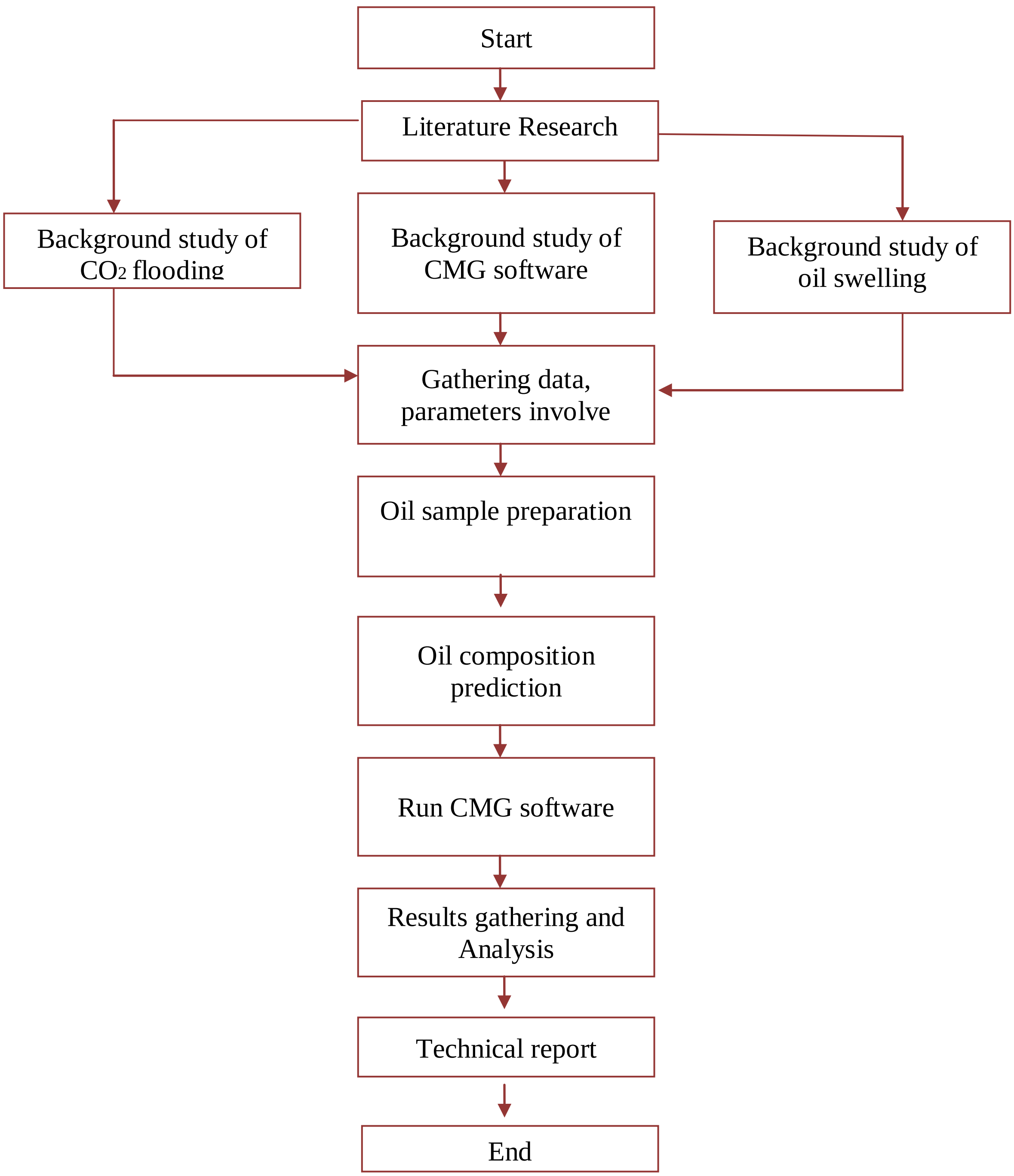
- Component characterization.
- PVT matching.
- Miscibility studies.
- Modelling of laboratory experiments, such as CCE, DV, & swelling test.
- Prediction of wax and asphaltene production.
- Surface separation facilities modelling.
- Generation of PVT data for CMG simulators.

WinProp is a fundamental and major tool for reservoir engineers, both in the laboratory and in the field. It has demonstrated its value in multi-phase processes. CMG's / WinProp is a basic component of advanced reservoir modelling and simulation (http://www.cmgroup.com/software/winprop.htm).

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification:



3.2 Tools:

- Gas chromatography; to characterize the composition of one oil sample.
- Recombination cell; to inject methane and CO_2 gas to the dead oil sample.
- CMG software.

3.3 Details of the procedure:

Throughout this project, there were some procedures was followed. This is to ensure that the project could be accomplished within the given timeframe.

3.3.1 Data collection:

This simulation study was made on five oil samples, the composition of the first sample was obtained experimentally by recombine dead oil sample and determining its composition using gas chromatography GC cell. The composition of the other oil samples were obtained from literature review.

3.3.2 Preparation of oil sample:

- **Gas chromatography GC:**

Light oil sample was collected and its characteristics and compositions were identified and measured using gas chromatography device (GC). The main purpose of identifying oil composition is to know the molecular weight of the dead oil sample and the number of moles of each component comprising this sample. This information is then needed in recombination process.

Table-1 shows the composition of dead oil sample.

Table – 1: Composition of dead oil sample No. 1

Component	Stock tank oil @ 0 psig, 60 ^{o}F
CO2	0.000
N2	0.000
C1	0.000
C2	0.000
C3	0.000
i-C4	0.000
n-C4	0.000
i-C5	0.000
n-C5	0.004
C6	1.864
C7	7.713
C8	5.997
C9	3.679
C10	4.679
C11+	76.068
total	100.000
S.G	0.836
MW	189.850

The following figures show the collected oil sample and the GC device that was used during experimental work.

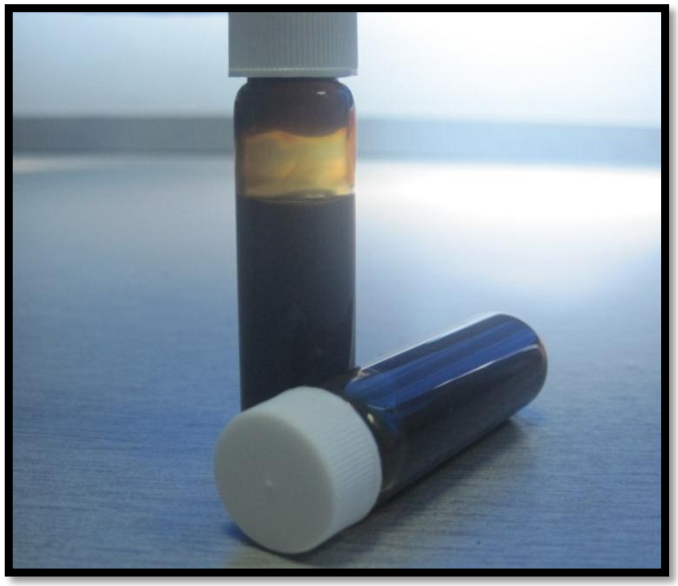


Figure – 3: Bottles of oil sample

Figure – 4: GC device

- **Recombination cell:**

After the composition of dead oil sample has been identified, it was recombined with methane and CO_2 gas to revive the dead oil samples.

Recombination cell is usually used to combine oil and gas samples to meet fluid properties at reservoir condition.

Details of recombined fluids:

1- Dead oil sample:

Oil volume to be recombined is 1100 cc.

Specific gravity (S.G) is 0.836 and molecular weight (MW) is 189.850 (S.G & MW values were obtained from GC).

Number of moles is then calculated using the following formulas:

$$\boxed{\rho o = S.G_o * \rho_w} \qquad \text{……………………………………………………… (1)}$$

$\rho_o = 0.836 * 1$

$\rho_o = 0.836$ g/cc

Where:

$\rho_o \equiv$ oil density

$\rho w \equiv$ water density

$S.G_o \equiv$ oil specific gravity

$$\boxed{\mathbf{m_o = \rho_o * v_o}} \quad \ldots\ldots (2)$$

$m_o = 0.836 * 1100$

$m_o = 919.6$ g

Where:

$m_o \equiv$ oil mass

$v_o \equiv$ oil volume

$$\boxed{\mathbf{no = mo / MW}} \quad \ldots\ldots (3)$$

$n_o = 919.6 / 189.850$

$n_o = 4.844$ moles

Where:

$n_o \equiv$ oil number of moles

$MW \equiv$ oil molecular weight

2- Methane gas (CH4):

400 cc of CH4 was transferred to recombination cell under the following condition:

Pressure = 800 psia (54.4 atm)

Temperature = 33 ^oC (306 ^oK)

Number of moles was calculated using equation of state EOS of real gas:

$$\boxed{\mathbf{P * V = z * n_{CH4} * R * T}} \quad \ldots\ldots (4)$$

n_{CH4} = (54.4 * 400) / (0.925 * 82.057 * 306)

n_{CH4} = 0.9103 moles

Where:

Z ≡ methane compressibility factor.

R ≡ real gas constant (82.057 cc.atm/◦K.mol)

Note: compressibility factor z was found to be 0.925 from natural gas compressibility chart as a function of pseudo reduced pressure and temperature (Ppr, Tpr), refer to APPENDIX-I ,with the following values of pseudo reduced pressure and temperature:

$$\boxed{\mathbf{P_{pc} = 709.604 - 58.718 * S.G}} \qquad \text{.. (5)}$$

$$\boxed{\mathbf{T_{pc} = 170.491 + 307.344 * S.G}} \qquad \text{.. (6)}$$

Methane specific gravity is 0.5573, substituting this value in Ppc & Tpc equations:

Ppc = 677 psia , Ppr = 1.2

Tpc = 341 ^{o}R , Tpr = 1.6

3- Carbon dioxide gas (CO2):

Based on the original reservoir oil composition, 600 cc of CO2 was transferred to recombination cell under the condition of:

Pressure = 500 psia (34.01 atm)

Temperature = 33 ^{o}C (91 ^{o}F)

The number of moles of CO2 was calculated using equation (9) EOS of real gas:

$$\boxed{\mathbf{P * V = z * n_{CO2} * R * T}}$$

n_{CO2} = (34.01 * 600) / (0.8913 * 82.057 * 306)

n_{CO2} = 0.9118 moles

Note: compressibility factor Z_{CO2} was found to be 0.8913. It was calculated using the following equation:

$$Z_{CO2} = a_0 + a_1 p + a_2 p^2 + a_3 p^3 + a_4 p^4$$

Where P is the atmospheric pressure and the values of a_0 to a_4 are functions of temperature in degrees Fahrenheit.

$$a_0(T) = b_0 + b_1 T + b_2 T^2 + b_3 T^3$$
$$a_1(T) = c_0 + c_1 T + c_2 T^2 + c_3 T^3$$
$$a_2(T) = d_0 + d_1 T + d_2 T^2 + d_3 T^3$$
$$a_3(T) = e_0 + e_1 T + e_2 T^2 + e_3 T^3$$
$$a_4(T) = f_0 + f_1 T + f_2 T^2 + f_3 T^3$$

The values $b_0 - b_3$, $c_0 - c_3$, $d_0 - d_3$, $e_0 - e_3$, $f_0 - f_3$ are obtained from the following regression (Obeida , Italic, 1997).

	Pure Carbon Dioxide
b_0	1.180E+01
b_1	-3.391E-01
b_2	3.503E-03
b_3	-1.198E-05
c_0	-3.456E-01
c_1	1.092E-02
c_2	-1.142E-04
c_3	3.955E-07
d_0	3.211E-03
d_1	-1.060E-04
d_2	1.136E-06
d_3	-4.008E-09
e_0	-1.179E-05
e_1	4.016E-07
e_2	-4.393E-09
e_3	1.573E-11
f_0	1.503E-08
f_1	-5.231E-10
f_2	5.810E-12
f_3	-2.106E-14

Thus, the total number of moles of the live oil (dead oil + CO_2 + CH_4) is:

$$n_t = n_o + n_{CO2} + n_{CH4}$$

$$n_t = 4.844 + 0.9118 + 0.9103 = 6.6661 \text{ moles.}$$

The figure below shows the recombination cell that was used to revive dead oil sample during experimental work.

Figure – 5: Recombination cell

After the live oil sample has been prepared, its composition was tabulated as shown in table – 2;

Table – 2: Composition of live oil sample No. 1

Component	Mole percentage (xi %)
CO2	13.6786
C1	13.6561
n-C5	0.00291
C6	1.35448
C7	5.60468
C8	4.35773
C9	2.67044
C10	3.40001
C11+	55.27509
C11+ MW	213.349
total	100.00
S.G	0.800
total MW	**146.1642**

The compositions of the other oil samples are shown in the following table. (Nancy, Italic., 1990)

Table – 3: Compositions of the other four live oil samples

Composition	oil-2	oil-3	oil-4	oil-5
N2	0.57	0.05	0.23	0.2
CO2	2.46	6.47	8.53	5.45
C1	36.37	9.58	21.72	30.9
C2	3.47	12	20.8	18.04
C3	4.05	6.83	4.82	5.45
i-C4	0.59	0.87	1.35	1.11
n-C4	1.34	3.78	3.47	2.56
i-C5	0.74	1.42	1.68	0.38
n-C5	0.83	2.62	2.11	2.18
C6	1.62	4.95	2.53	1.93
C7+	47.96	51.43	32.76	31.8
C7+ SG	0.9594	0.9151	0.8533	0.823
C7+ MW	329	271	219	197
total	100	100	100	100
total MW	171.4	151.6	95.1	83.6

3.3.3 Simulation using CMG:

Oil compositions in tables (2) and (3) were entered to the CMG software in WinProp window, oil components of each oil sample were split and grouped for more accurate result. Then regression was made using saturation pressure of each sample taken from relevant field data.

After all needed data has been entered and generated using Peng-Robinson (1978) EOS; swelling test was run for each sample at different CO_2 concentrations stating from 20% mole, 40% mole, 50% mole and 60% mole.

CCE test was run starting from high pressure (6000 psi) decreasing down to (1000 psi) to detect saturation pressure at each CO_2 concentrations. And finally result and graphs were obtained.

3.4 Gantt Chart for FYP I & FYP II:

Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of the project topic														
Preliminary research work														
Preliminary report submission						✸								
Proposal Defence (Oral Presentation)														
Project Work Continues														
Submission of Interim draft report												✸		
Submission of Interim Report													✸	

Figure - 6: Gantt chart for FYP I

Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Lab registration & start experimental work and simulation															
Submission progress report								✸							
Simulation work continue															
Pre - EDX											✸				
Submission of draft report												✸			
Submission of dissertation (soft bound)													✸		
Submission of Technical Paper													✸		
Final oral presentation														✸	
Submission of project dissertation (hard bound)															✸

Figure - 7: Gantt chart for FYP II

Legend :	
Deadline	✸
Current progress	

CHAPTER 4

RESULT AND DISCUSSION

4.1 Result:

Compositions and properties of five oil samples were entered to CMG software; swelling test and CCE test were run. The following result was obtained.

4.1.1 Result of oil sample No. 1:

The bubble point pressure of virgin oil was found to be 1889.9 psia. As the concentration of CO_2 increases, the bubble point pressure increases as well.

The following figure summarizes the relationship between pressure and relative volume of sample No. 1 for each CO_2 concentration. It indicates the value of bubble point pressure at each CO_2 concentration where the relative volume equals to one. For detailed information Refer to APPENDIX II – result of sample No. 1 to see the tables of relative volume & pressures at each CO_2 concentration during CCE test.

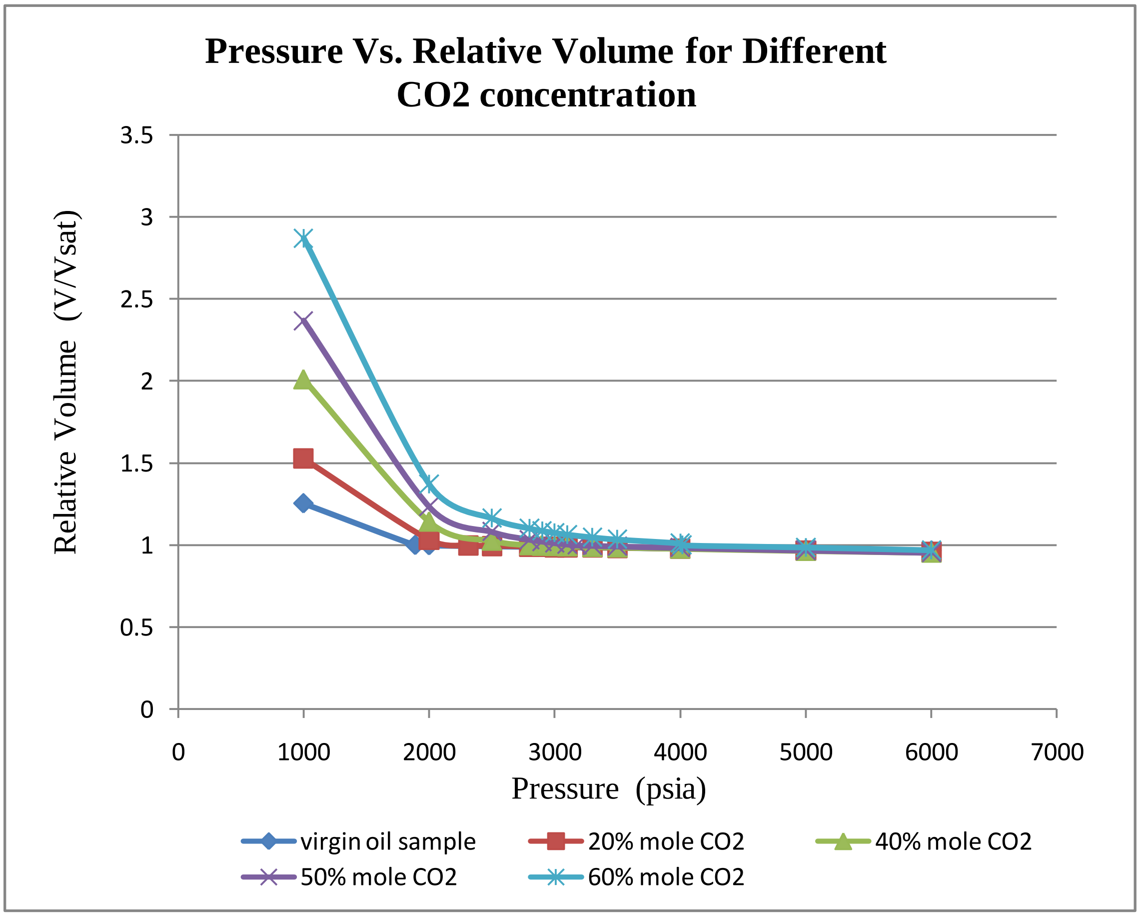


Figure – 8: Relationship between pressure and relative volume Oil sample No. 1

The swelling factor of sample No. 1 was found to be 1.076 at 20% mole of CO_2; which means the volume of oil has increased by 7.6% after injecting 20% mole of CO_2. As observed, swelling factor will increase as the mole percentage of injected CO_2 increases. The same phenomenon was observed by Ghedan (2009), during his study on laboratory experience of CO_2-EOR flooding.

For 40%, 50%, and 60% mole of CO_2, the oil volume increment was found to be 20.3%, 30%, & 42.5 % respectively. The following table shows the swelling factor and P_b for each CO_2 concentration.

Table – 4: Swelling test result for oil sample No.1

CO_2 Mole %	P_b (psia)	S.F
0	1889.9	1
20	2313.96	1.076
40	2896.26	1.203
50	3379.52	1.3
60	4016.15	1.425

The following figure shows the relationship between bubble point pressure and swelling factor for different CO_2 concentrations.

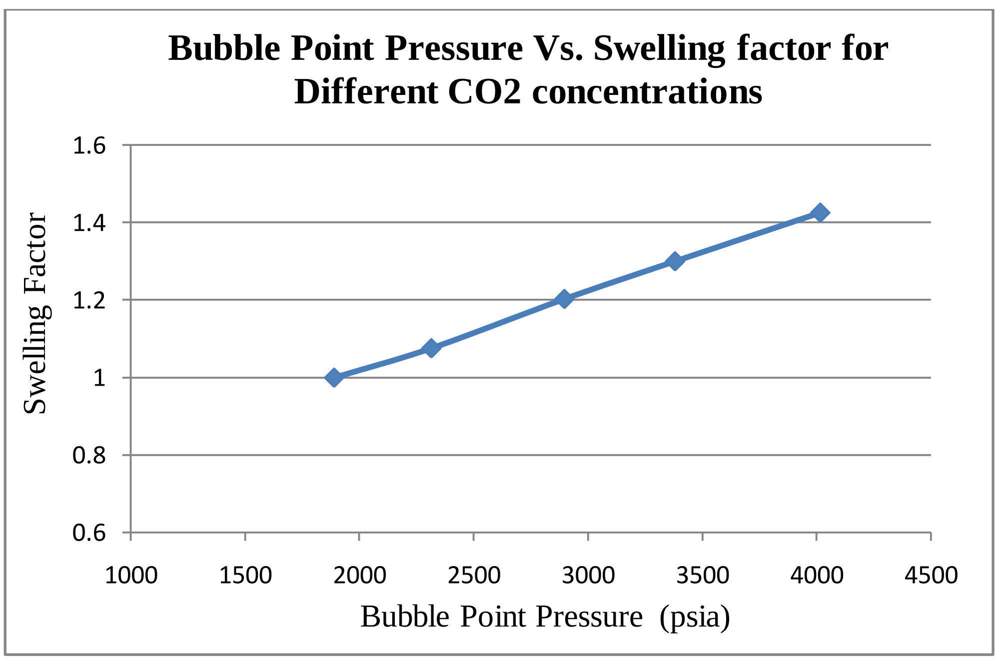


Figure – 9: Relationship between bubble point pressure and swelling factor Oil sample No. 1

The figure below shows the relationship between CO_2 concentration and swelling factor.

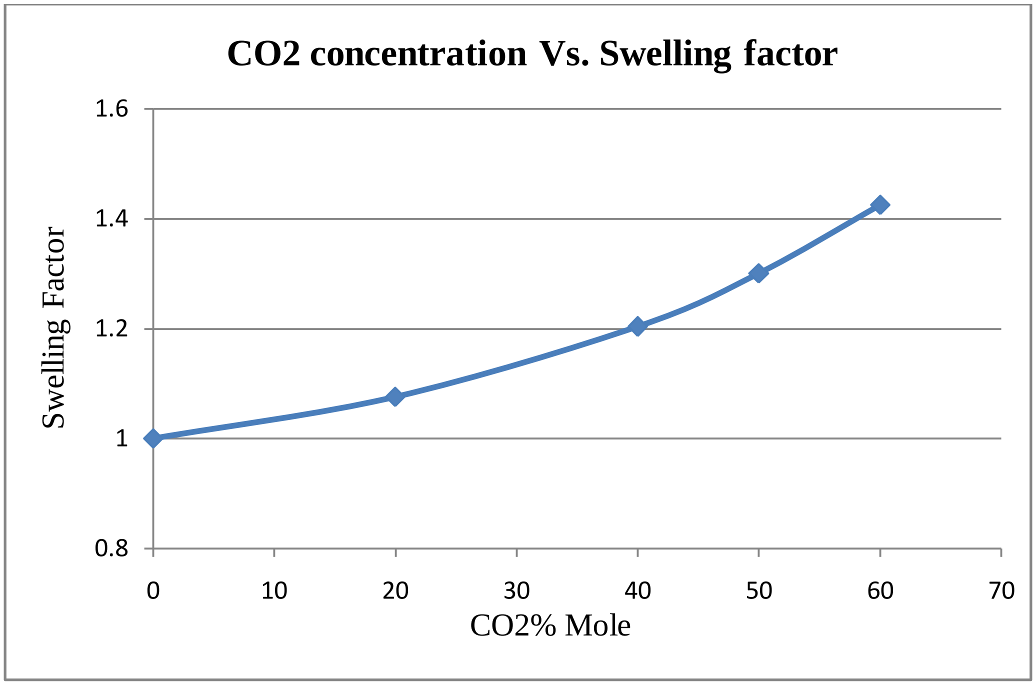


Figure – 10: Relationship between CO_2 mole% and swelling factor
Oil sample No. 1

4.1.2 Result of oil sample No. 2:

The bubble point pressure of virgin oil was found to be 2629.7 psia. As the concentration of CO_2 increases, the bubble point pressure increases as well.

The following figure summarizes the relationship between pressure and relative volume for each CO_2 concentration which It indicates the value of bubble point pressure at each CO_2 concentration where the relative volume equals to one. For detailed information Refer to APPENDIX II – result of oil sample No. 2, to see the tables of relative volume & pressures at each CO_2 concentration during CCE test.

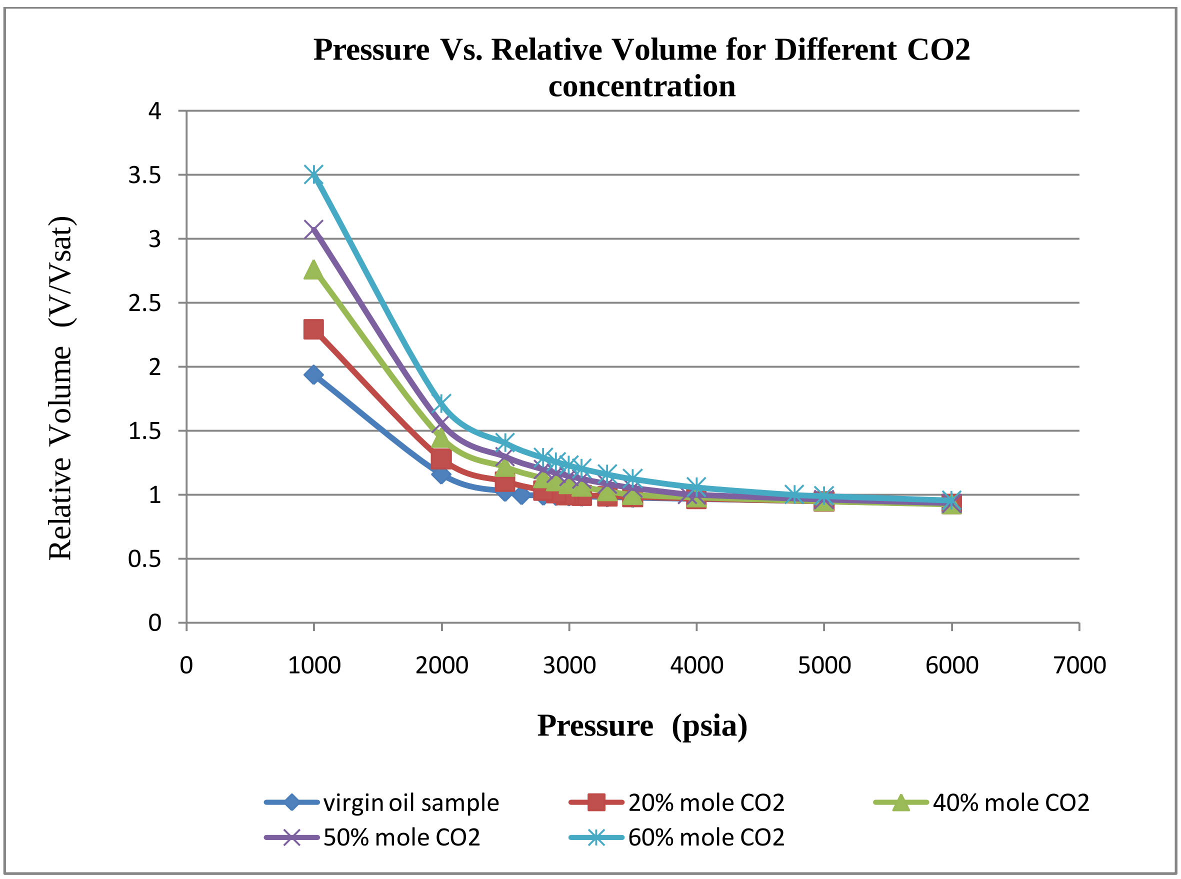


Figure – 11: Relationship between pressure and relative volume Oil sample No. 2

The swelling factor of this sample was found to be 1.101 for 20% mole of CO_2; which means the volume of oil has increased by 10.1% after injecting 20% mole of CO_2. As observed, swelling factor will increase as the mole percentage of injected CO_2 increases.

For 40%, 50%, and 60% mole of CO_2, the oil volume increment was found to be 26.3%, 38.5%, & 53.9 % respectively. The following table shows the swelling factor and P_b for each CO_2 concentration.

Table – 5: Swelling test result of oil sample No.2

CO_2 Mole %	P_b (psia)	S.F
0	2629.7	1
20	2975.18	1.101
40	3495.29	1.263
50	3927.81	1.385
60	4767.66	1.539

The following figure shows the relationship between bubble point pressure and swelling factor for different CO_2 concentrations.

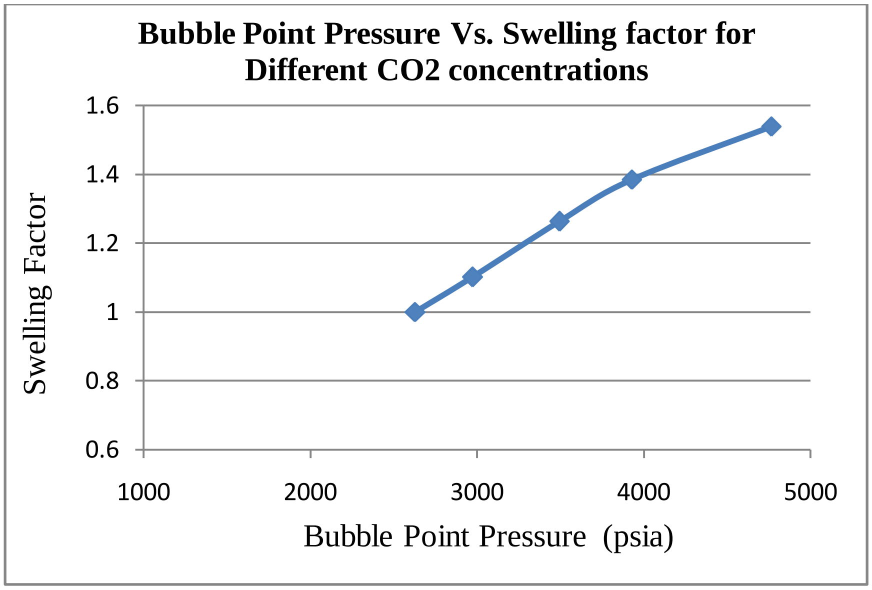


Figure – 12: Relationship between bubble point pressure and swelling factor Oil sample No. 2

The figure below shows the relationship between CO_2 concentration and swelling factor.

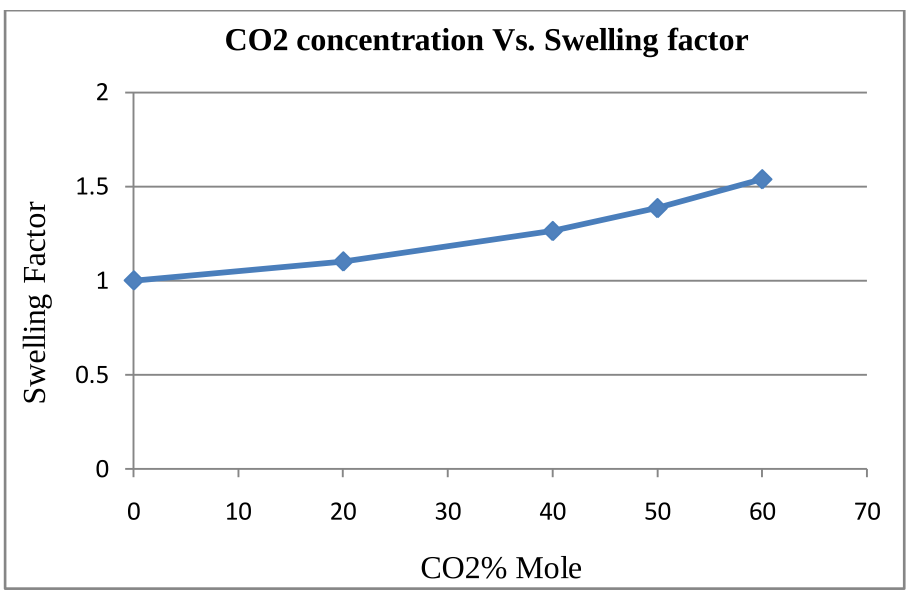


Figure – 13: Relationship between CO_2 mole% and swelling factor Oil sample No. 2

4.1.3 Result of oil sample No. 3:

The bubble point pressure of base case condition was found to be 1576.52 psia. As the concentration of CO_2 increases, the bubble point pressure increases as well.

The following figure summarizes the relationship between pressure and relative volume for each CO_2 concentration. For detailed information Refer to APPENDIX II – result of oil sample No.3, which contains tables of relative volumes pressures at each CO_2 concentration during CCE test.

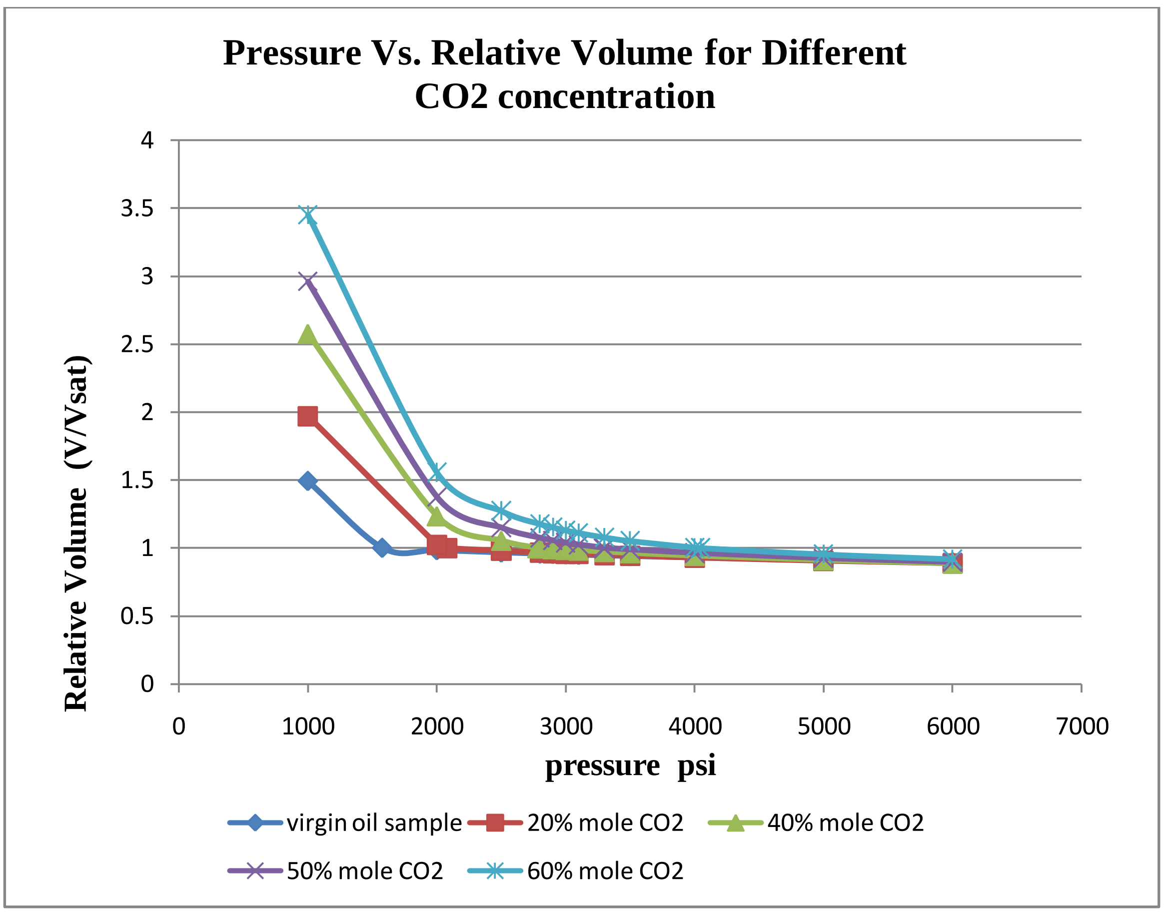


Figure – 14: Relationship between pressure and relative volume Oil sample No. 3

The swelling factor was found to be 1.117 for 20% mole of CO_2; which means the volume of oil has increased by 11.7% after injecting 20% mole of CO_2. As observed, swelling factor will increase as the mole percentage of injected CO_2 increases.

For 40%, 50%, and 60% mole of CO_2, the oil volume increment was found to be 30.4%, 44.1%, & 62.5 % respectively. The following table shows the swelling factor and P_b for each CO_2 concentration.

Table – 6: Swelling test result for oil sample No.3

CO_2 Mole %	P_b (psia)	S.F
0	1576.52	1
20	2078.77	1.117
40	2780.08	1.304
50	3294.08	1.441
60	4046.52	1.625

The following figure shows the relationship between bubble point pressure and swelling factor for different CO_2 concentrations.

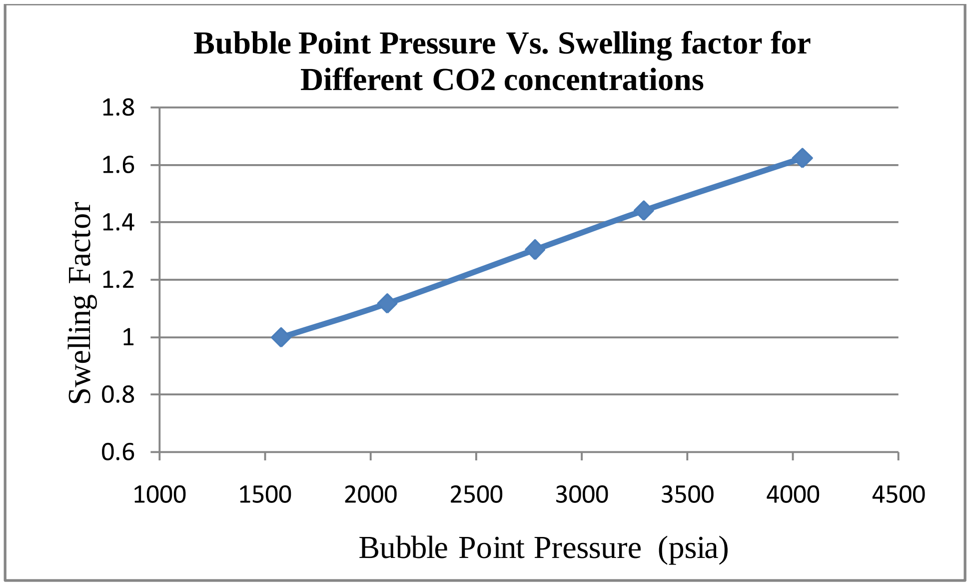


Figure – 15: Relationship between bubble point pressure and swelling factor Oil sample No.3

The figure below shows the relationship between CO_2 concentration and swelling factor.

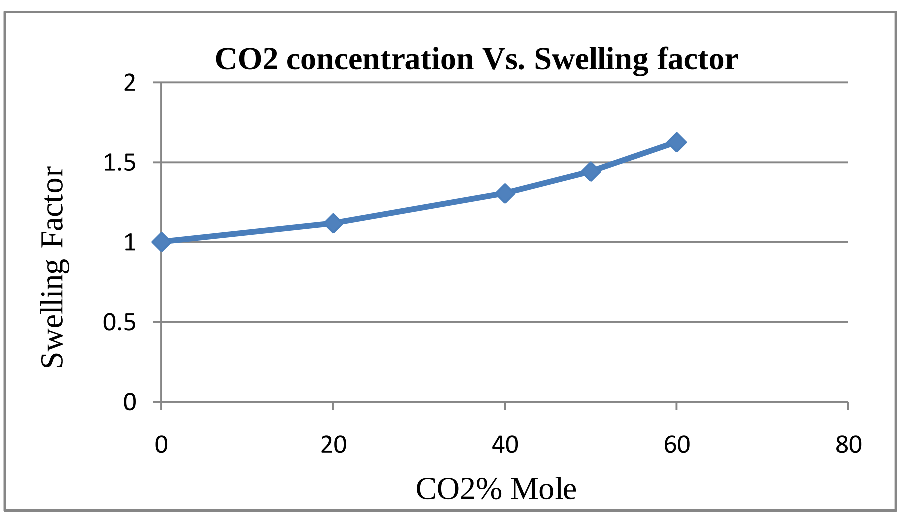


Figure – 16: Relationship between CO_2 mole% and swelling factor Oil sample No. 3

4.1.4 Result of oil sample No. 4:

The bubble point pressure of virgin oil was found to be 2197.36 psia. As the concentration of CO_2 increases, the bubble point pressure increases as well.

The following figure summarizes the relationship between pressure and relative volume for each CO_2 concentration. For detailed information Refer to APPENDIX II – result of oil sample No. 4, which contains tables of relative volumes & pressures at each CO_2 concentration during CCE test.

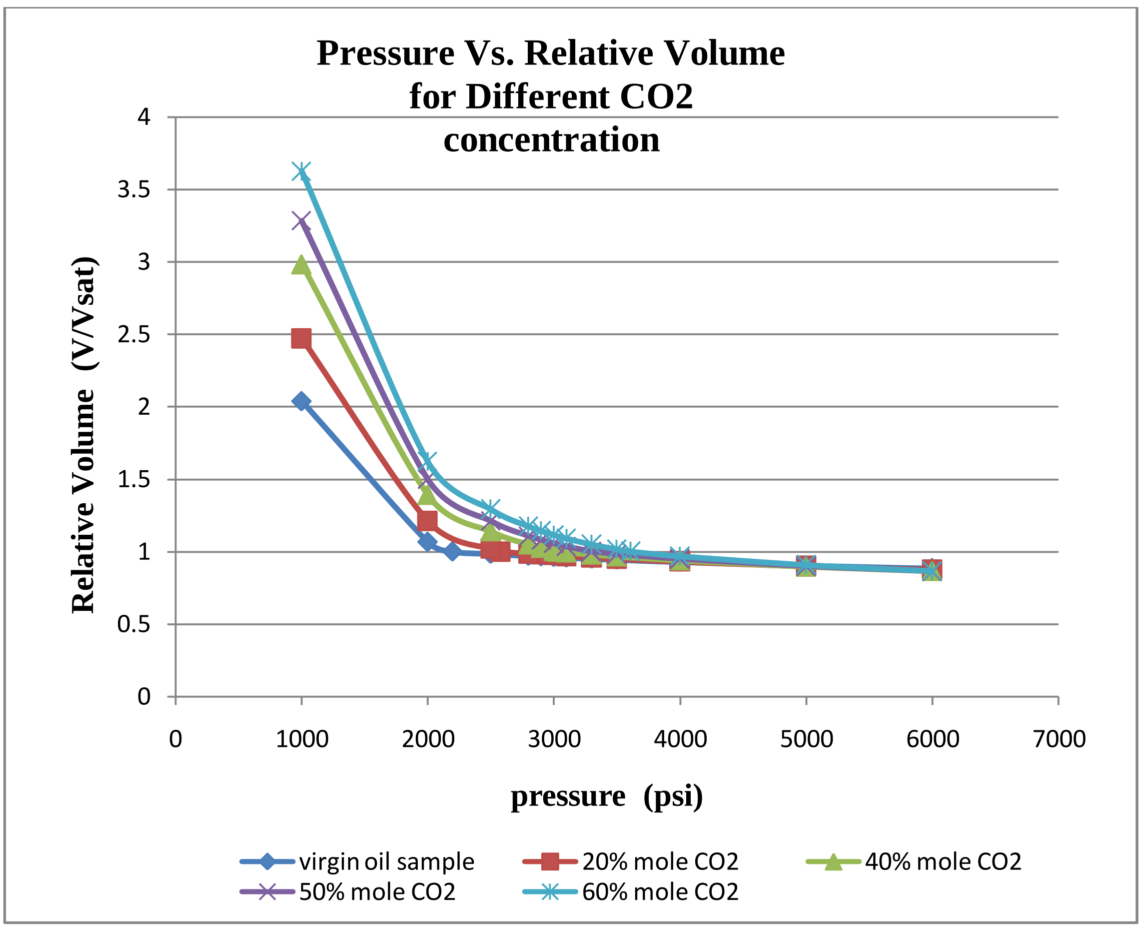


Figure – 17: Relationship between pressure and relative volume
Oil sample No. 4

The swelling factor was found to be 1.14 for 20% mole of CO_2; which means the volume of oil has increased by 14 % after injecting 20% mole of CO_2. As observed, swelling factor will increase as the mole percentage of injected CO_2 increases.

For 40%, 50%, and 60% mole of CO_2, the oil volume increment was found to be 37 %, 55.1 %, & 81.6 % respectively. The following table shows the swelling factor and P_b for each CO_2 concentration.

Table – 7: Swelling test result for oil sample No.4

CO_2 Mole %	P_b (psia)	S.F
0	2197.36	1
20	2575.79	1.14
40	3027.77	1.37
50	3298.8	1.551
60	3611.23	1.816

The following figure shows the relationship between bubble point pressure and swelling factor for different CO_2 concentrations.

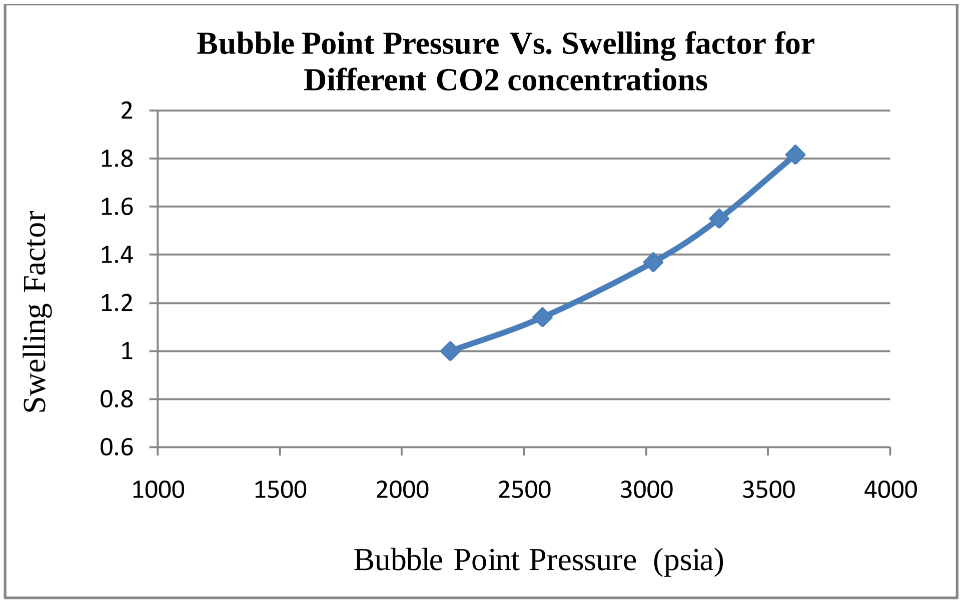


Figure – 18: Relationship between bubble point pressure and swelling factor Oil sample No. 4

The figure below shows the relationship between CO_2 concentration and swelling factor.

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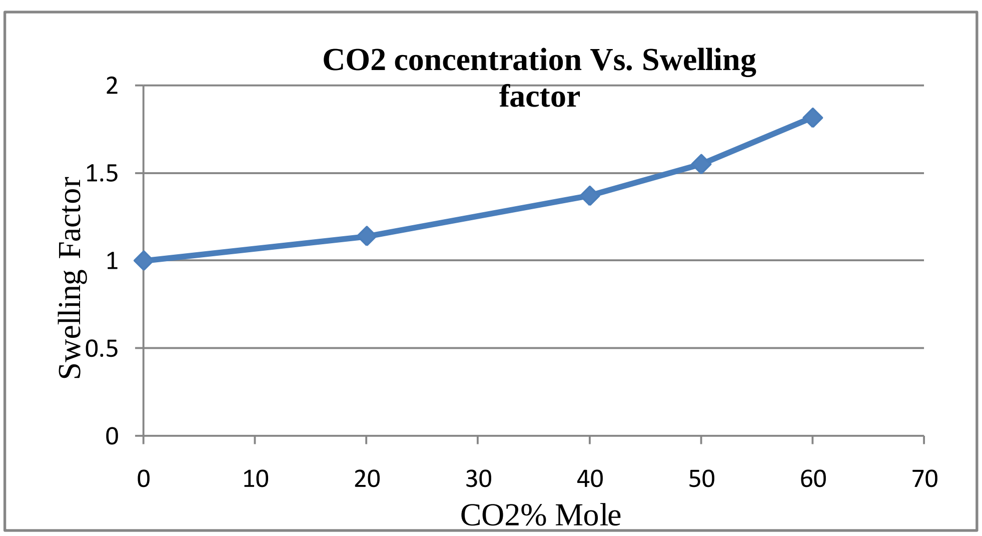

Figure – 19: Relationship between CO_2 mole% and swelling factor Oil sample No. 4

4.1.5 Result of oil sample No. 5:

The bubble point pressure of virgin oil was found to be 2771.9 psia. As the concentration of CO_2 increases, the bubble point pressure increases as well.

The following figure summarizes the relationship between pressure and relative volume for each CO_2 concentration. For detailed information Refer to APPENDIX II – result of oil sample No. 5, which contains tables of relative volumes vs pressures at each CO_2 concentration during CCE test.

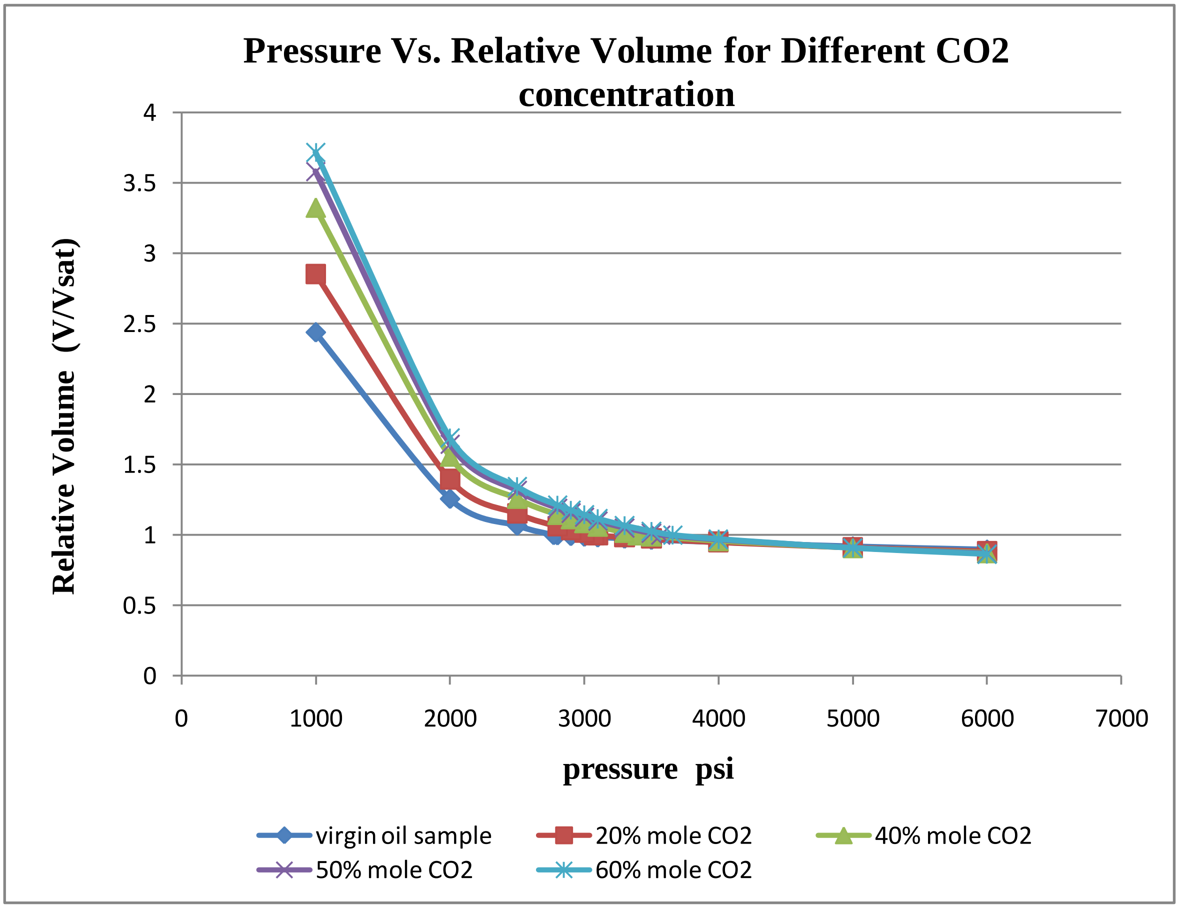

Figure – 20: Relationship between pressure and relative volume Oil sample No. 5

The swelling factor was found to be 1.154 for 20% mole of CO_2; which means the volume of oil has increased by 15.4% after injecting 20% mole of CO_2. As observed, swelling factor will increase as the mole percentage of injected CO_2 increases.

For 40%, 50%, and 60% mole of CO_2, the oil volume increment was found to be 41.3%, 62.1%, & 90.1 % respectively. The following table shows the swelling factor and P_b for each CO_2 concentration.

Table – 8: Swelling test result for oil sample No.5

CO_2 Mole %	**P_b (psia)**	**S.F**
0	2771.9	1
20	3071.67	1.154
40	3397.38	1.413
50	3570.65	1.621
60	3658.81	1.901

The following figure shows the relationship between bubble point pressure and swelling factor for different CO_2 concentrations.

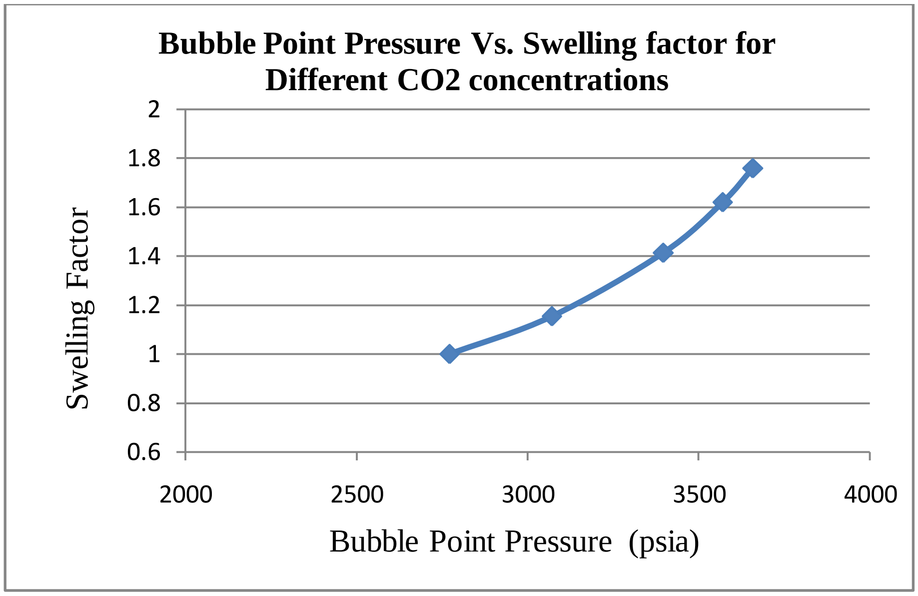

Figure – 21: Relationship between bubble point pressure and swelling factor Oil sample No. 5

The figure below shows the relationship between CO_2 concentration and swelling factor.

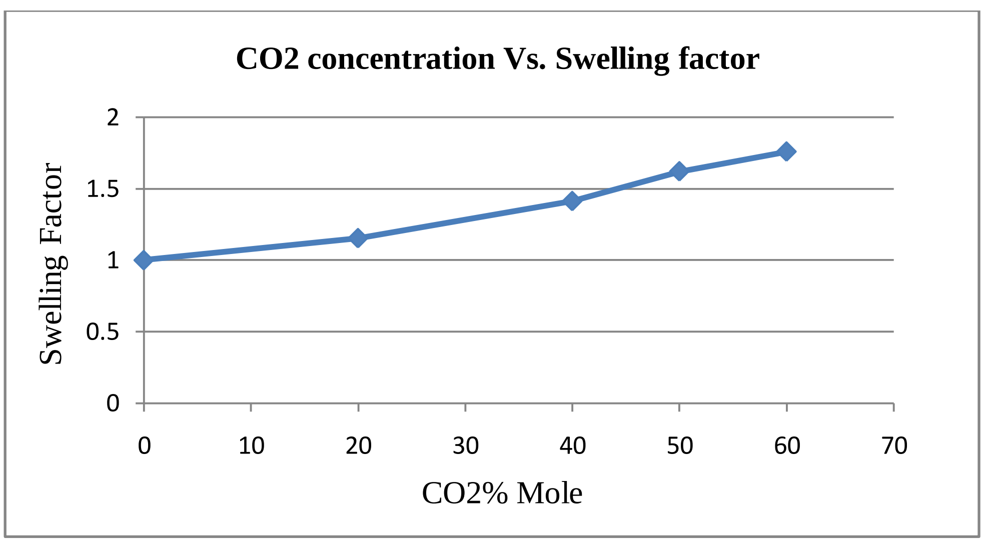

Figure – 22: Relationship between CO_2 mole% and swelling factor Oil sample No. 5

4.2 Discussion:

Based on CCE test result, sample No. 3 has the minimum initial P_b of 1576.52 psia while sample No. 5 has the maximum initial P_b of 2771.9 psia. The increment of bubble point pressure for samples No. 1, 2, and 3 during CO_2 injection is following almost the same slop for different pressure values. While samples No.4, and 5 are having different slop of P_b pressure increment during injection process. The increment of saturation pressure or bubble point pressure is due to phase behavior change after injecting CO_2 gas. This difference in slops refers to different oil samples have different behavior with CO_2 injection.

Samples No. 1 & 3 start to have the same bubble point pressure at 55% mole of CO_2 , while samples No. 4 and 5 are having almost the same P_b at 60% mole of the injected CO_2.

The following figure shows the trend of P_b increment of the five oil samples.

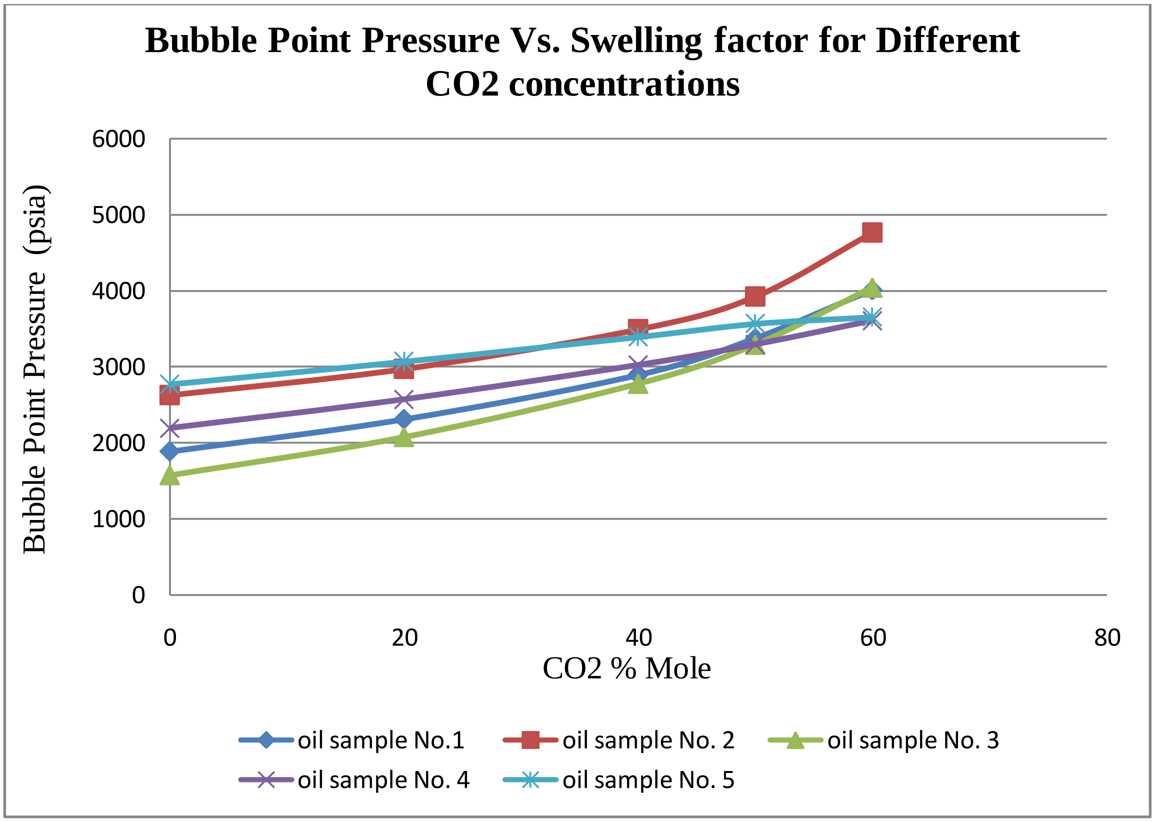

Figure – 23: Relationship between Bubble Point Pressures Vs. CO_2 % Mole For five oil samples

Although all oil samples are light oils (having API greater than 10), it is obvious from the composition and API gravities of the five oil samples that, oil sample No. 5 is lightest sample since its API gravity is the greatest among this group having a value of 40 ^{o}API, which explains the reason of having greatest swelling factor.

In terms of swelling factor, lighter oils usually have higher swelling factor than heavier. Based on API, sample No.2 (19 ^{o}API) is heavier than sample No.1 (38 ^{o}API), and yet the swelling factor of sample No.2 is higher than the one of sample No.1 as shown in figure - 24. This is because of the composition of both samples, since sample No.2 is containing intermediate components such as C2, C3, and C4, while Sample No. 1 is not. These intermediate components then will be extracted by CO_2 gas causing higher swelling factor. Table - 9 shows the comparison of S.F result at different CO_2 concentration for the five oil samples.

Table – 9: Summary of simulation result

Sample Name	Oil-1	Oil-2	Oil-3	Oil-4	Oil-5
API gravity	38	19	30	37	40
P_b (psia)	1889.9	2629.7	1576.52	2197.36	2771.9
S.F @ 20% mole CO_2	1.076	1.101	1.117	1.14	1.154
S.F @ 40% mole CO_2	1.203	1.263	1.304	1.37	1.413
S.F @ 50% mole CO_2	1.3	1.385	1.441	1.551	1.621
S.F @ 60% mole CO_2	1.425	1.539	1.625	1.816	1.901

While comparing the result of swelling factor it was found that, the difference between swelling factors of the five oil samples at 20% mole CO_2 is not much, but as the concentration of CO_2 increases, the difference between swelling factors of the samples will be higher. The following figure shows the difference in oil volume increment (swelling factor) at each CO_2 concentration.

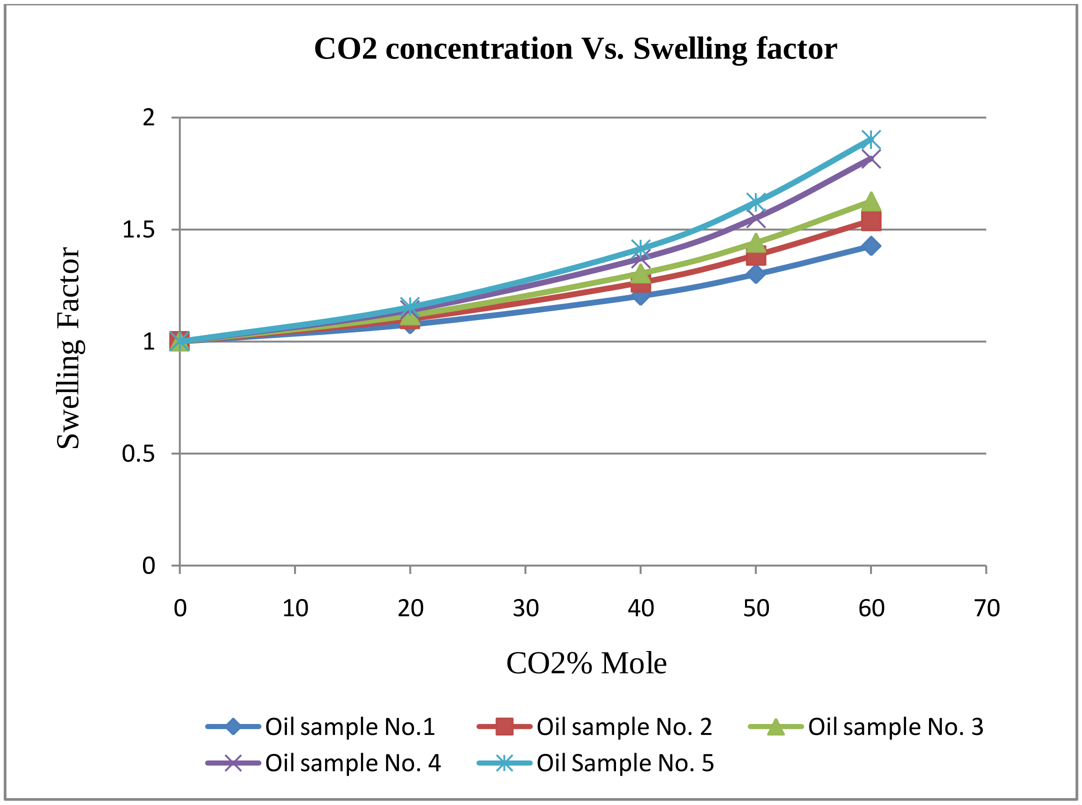

Figure – 24: Relationship CO_2 concentration and swelling factor For five oil samples

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusion:

Oil swelling is directly proportional to the concentration of the injected CO_2, the factor directing this relationship is called oil swelling factor. It varies from field to another; it also depends on oil properties as well as reservoir condition.

Oil swelling factor is defined as the ratio of the volume of the oil- CO_2 mixture to the initial volume of gas free oil at standard pressure and temperature.

The swelling factors of five oil samples were determined, analytical analysis was made on the result.

In a comparison study between five oil samples, it was found that, the oil sample No.5 has highest swelling factor since it is the lightest sample having gravity of 40 ^{o}API.

Although CO_2 resources are available and could be easily obtained with low cost, the optimum amount of injected CO_2 must be determined in order to meet the economical and technical factors, thus it does not depend only upon swelling factor, it is also dependent on the economic recovery factor.

Based on the technical / oil swelling factors, CO_2 flooding is considered as feasible process up to 60% mole for all oil samples, since the swelling factors did not reach the critical point, beyond which the swelling factor start to decrease.
For complete EOR evaluation, economical factors must be considered in parallel with technical factors.

5.2 Recommendations:

Conducting a CCE test experimentally using PVT cell will result in more accurate result of saturation pressures and swelling factors.

The optimum range (minimum and maximum amount) of CO_2 has to be identified not only based on swelling factor, but also based on other technical factor such as asphaltene precipitation which is affecting reservoir permeability, as well as economical factors which is based on recovery factor of each CO_2 concentration, as higher swelling factor does not usually result in higher oil recovery.

The selection of the optimum mole percentage of injected CO_2 is based on three important factors:

- Oil swelling factor.
- Asphaltene precipitation.
- Oil recovery factor.

These factors indicate the technical and economical visibility and effectiveness of the CO2 injection process.

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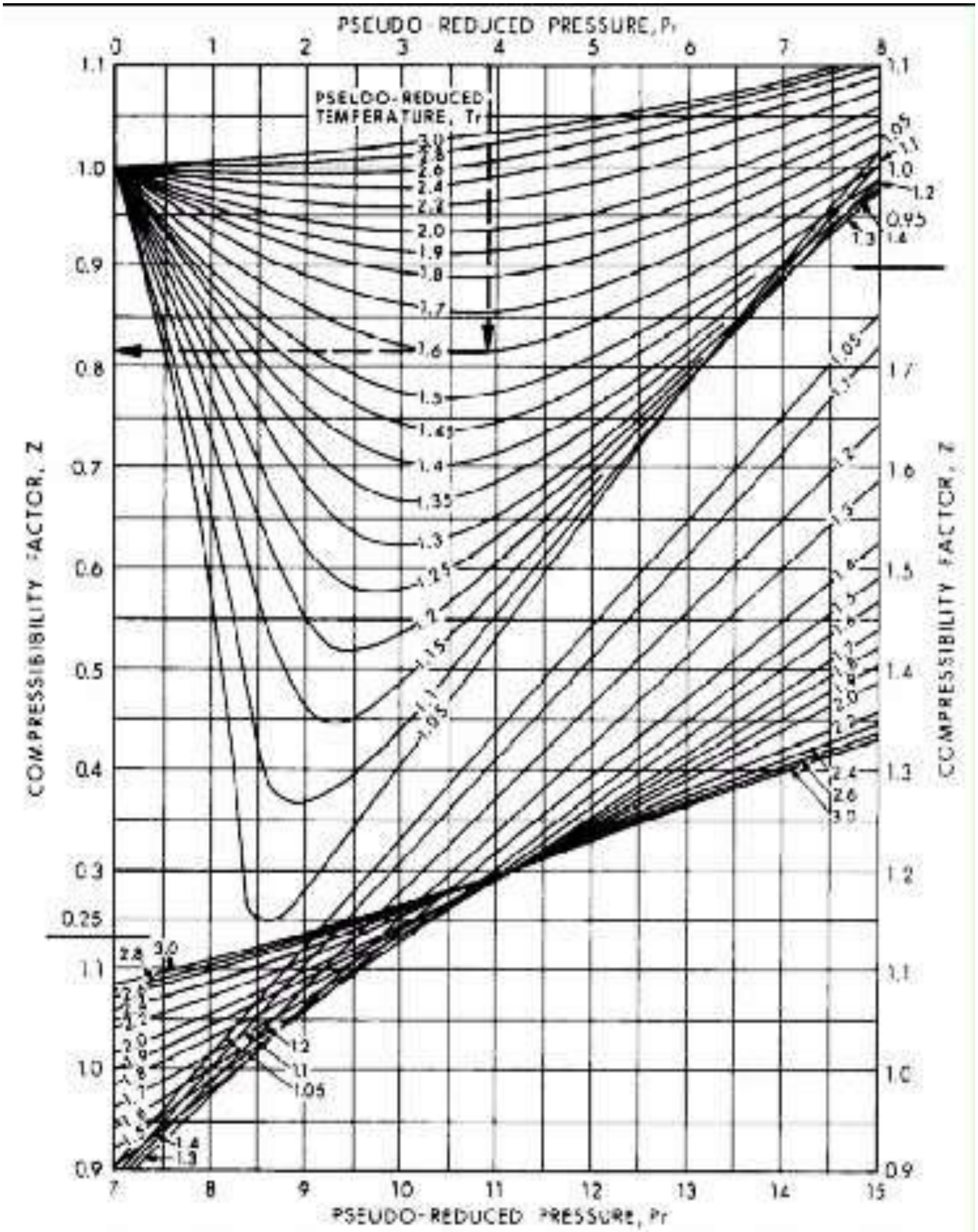
Websites:

http://www.cmgroup.com/company/aboutcmg.htm

http://www.cmgroup.com/software/winprop.htm

APPENDIX I

METHANE COMPRESSIBILITY FACTOR CHART



APPENDIX II

CCE TEST RESULT (RELATIV VOLUME TABLES)

Result of oil sample No. 1

CCE result of virgin oil sample No.1

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.9655
5000	0.972
4000	0.9795
3500	0.9837
3300	0.9854
3100	0.9872
3000	0.9882
2900	0.9891
2800	0.9901
2500	0.993
2000	0.9983
1889.9	1
1000	1.2549

CCE result of 20% CO_2 Oil sample No.1

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.9605
5000	0.9687
4000	0.9783
3500	0.9836
3300	0.9859
3100	0.9883
3000	0.9895
2900	0.9907
2800	0.992
2500	0.9959
2313.96	1
2000	1.0329
1000	1.5273

CCE result of 40% CO_2 Oil sample No.1

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.9548
5000	0.9659
4000	0.979
3500	0.9864
3300	0.9896
3100	0.993
3000	0.9947
2900	0.9965
2896.26	1
2800	1.0228
2500	1.0277
2000	1.1439
1000	2.0111

CCE result of 50% CO_2 Oil sample No.1

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.955
5000	0.9683
4000	0.9843
3500	0.9935
3300	0.9975
3379.52	1
3100	1.0056
3000	1.0137
2900	1.0232
2800	1.0345
2500	1.082
2000	1.235
1000	2.3681

CCE result of 60% CO_2 Oil sample No.1

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.9705
5000	0.9874
4016.15	1
4000	1.012
3500	1.0354
3300	1.0485
3100	1.0655
3000	1.076
2900	1.0882
2800	1.1027
2500	1.1646
2000	1.3726
1000	2.8706

Result of oil sample No. 2

CCE result of virgin oil sample No.2

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.9351
5000	0.9495
4000	0.9672
3500	0.9778
3300	0.9824
3100	0.9873
3000	0.9898
2900	0.9925
2800	0.9952
2629.7	1
2500	1.0253
2000	1.1607
1000	1.938

CCE result of 20% CO_2 Oil sample No.2

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.9292
5000	0.9471
4000	0.9696
3500	0.9832
3300	0.9893
3100	0.9958
3000	0.9991
2975.18	1
2900	1.0136
2800	1.0332
2500	1.1037
2000	1.2805
1000	1.415

CCE result of 40% CO_2 Oil sample No.2

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.9269
5000	0.9504
4000	0.9808
3500	0.9998
3495.29	1
3300	1.0288
3100	1.0639
3000	1.0841
2900	1.1061
2800	1.1303
2500	1.219
2000	1.4461
1000	2.7611

CCE result of 50% CO_2 Oil sample No.2

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.9324
5000	0.9602
4000	0.9969
3927.81	1
3500	1.051
3300	1.0829
3100	1.1215
3000	1.1438
2900	1.1684
2800	1.1955
2500	1.2957
2000	1.5557
1000	3.0721

CCE result of 60% CO_2 Oil sample No.2

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.9564
5000	0.9906
4767.66	1
4000	1.0586
3500	1.1241
3300	1.1602
3100	1.2041
3000	1.2296
2900	1.2578
2800	1.2891
2500	1.4054
2000	1.7111
1000	3.5035

Result of oil sample No.3:

CCE result of virgin oil sample No.3

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.8953
5000	0.9101
4000	0.9282
3500	0.9391
3300	0.9438
3100	0.9488
3000	0.9515
2900	0.9542
2800	0.9569
2500	0.9658
2000	0.9828
1576.52	1
1000	1.4909

CCE result of 20% CO_2 Oil sample No.3

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.888
5000	0.9064
4000	0.9296
3500	0.9438
3300	0.9501
3100	0.9568
3000	0.9603
2900	0.964
2800	0.9678
2500	0.98
2078.77	1
2000	1.0245
1000	1.9706

CCE result of 40% CO_2 Oil sample No.3

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.8872
5000	0.9115
4000	0.9433
3500	0.9634
3300	0.9725
3100	0.9824
3000	0.9876
2900	0.9931
2800	0.9988
2780.08	1
2500	1.0548
2000	1.2356
1000	2.578

CCE result of 50% CO_2 Oil sample No.3

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.8953
5000	0.9243
4000	0.963
3500	0.9881
3300	0.9996
3294.08	1
3100	1.0237
3000	1.0383
2900	1.0548
2800	1.0736
2500	1.1485
2000	1.3744
1000	2.9625

CCE result of 60% CO_2 Oil sample No.3

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.9178
5000	0.9535
4046.52	1
4000	1.0035
3500	1.0517
3300	1.0781
3100	1.1108
3000	1.1301
2900	1.1519
2800	1.1765
2500	1.273
2000	1.5557
1000	3.4515

Result of oil sample No. 4:

CCE result of virgin oil sample No.4

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.8844
5000	0.9041
4000	0.9291
3500	0.9445
3300	0.9513
3100	0.9587
3000	0.9626
2900	0.9666
2800	0.9708
2500	0.9844
2197.36	1
2000	1.0666
1000	2.0382

CCE result of 20% CO_2 Oil sample No.4

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.8748
5000	0.899
4000	0.9306
3500	0.9507
3300	0.9598
3100	0.9696
3000	0.9749
2900	0.9804
2800	0.9861
2575.79	1
2500	1.0198
2000	1.2114
1000	2.4718

CCE result of 40% CO_2 Oil sample No.4

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.8663
5000	0.8974
4000	0.9395
3500	0.9673
3300	0.9802
3100	0.9945
3027.77	1
3000	1.0054
2900	1.0263
2800	1.0498
2500	1.1404
2000	1.3922
1000	2.9844

CCE result of 50% CO_2 Oil sample No.4

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.8644
5000	0.9003
4000	0.9502
3500	0.9839
3300	0.9999
3298.9	1
3100	1.0356
3000	1.0569
2900	1.0808
2800	1.1078
2500	1.2114
2000	1.4986
1000	3.2833

CCE result of 60% CO_2 Oil sample No.4

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.8657
5000	0.9079
4000	0.9682
3611.23	1.0000
3500	1.0158
3300	1.049
3100	1.0904
3000	1.1149
2900	1.1424
2800	1.1733
2500	1.292
2000	1.6201
1000	3.625

Result of oil sample No. 5:

CCE result of virgin oil sample No.5

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.8956
5000	0.9184
4000	0.9479
3500	0.9664
3300	0.9747
3100	0.9836
3000	0.9884
2900	0.9933
2800	0.9985
2771.9	1
2500	1.0667
2000	1.2573
1000	2.4391

CCE result of 20% CO_2 Oil sample No.5

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.8853
5000	0.9134
4000	0.9508
3500	0.975
3300	0.9861
3100	0.9982
3071.67	1
3000	1.015
2900	1.0377
2800	1.0627
2500	1.1553
2000	1.3971
1000	2.8548

CCE result of 40% CO_2 Oil sample No.5

Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.8736
5000	0.9093
4000	0.9588
3500	0.9921
3397.38	1
3300	1.0182
3100	1.0616
3000	1.0867
2900	1.1145
2800	1.1453
2500	1.2595
2000	1.5584
1000	3.3241

CCE result of 50% CO_2 Oil sample No.5

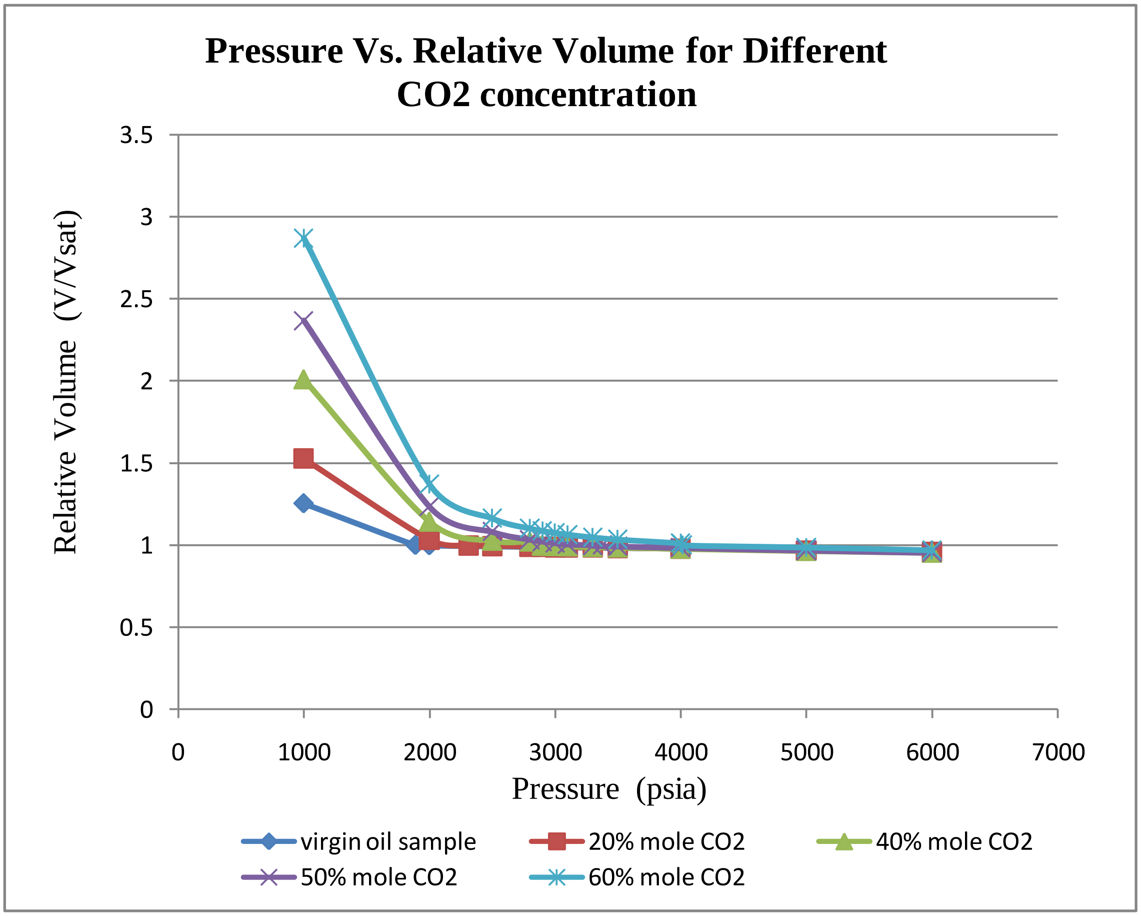
Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.8674
5000	0.9082
4000	0.9662
3570.65	1
3500	1.0119
3300	1.0505
3100	1.0978
3000	1.1252
2900	1.1557
2800	1.1895
2500	1.3155
2000	1.646
1000	3.582

CCE result of 60% CO_2 Oil sample No.5

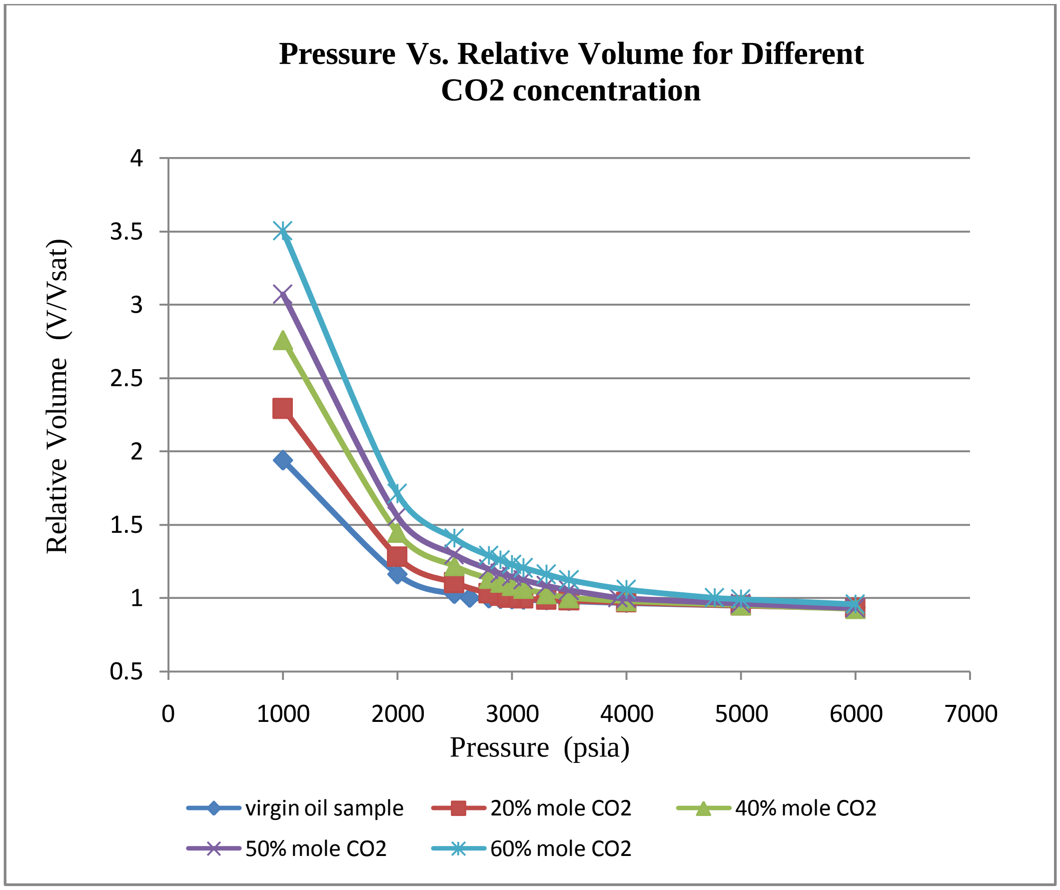
Pressure (psia)	Rel. Vol. (V/Vsat)
6000	0.8642
5000	0.908
4000	0.971
3658.81	1.0000
3500	1.0266
3300	1.0668
3100	1.116
3000	1.1447
2900	1.1766
2800	1.212
2500	1.3441
2000	1.6914
1000	3.7176

APPENDIX III

CCE TEST RESULT (RELATIVE VOLUME GRAPHS)



Relationship between pressure and relative volume
Oil sample No. 1



Relationship between pressure and relative volume
Oil sample No. 2

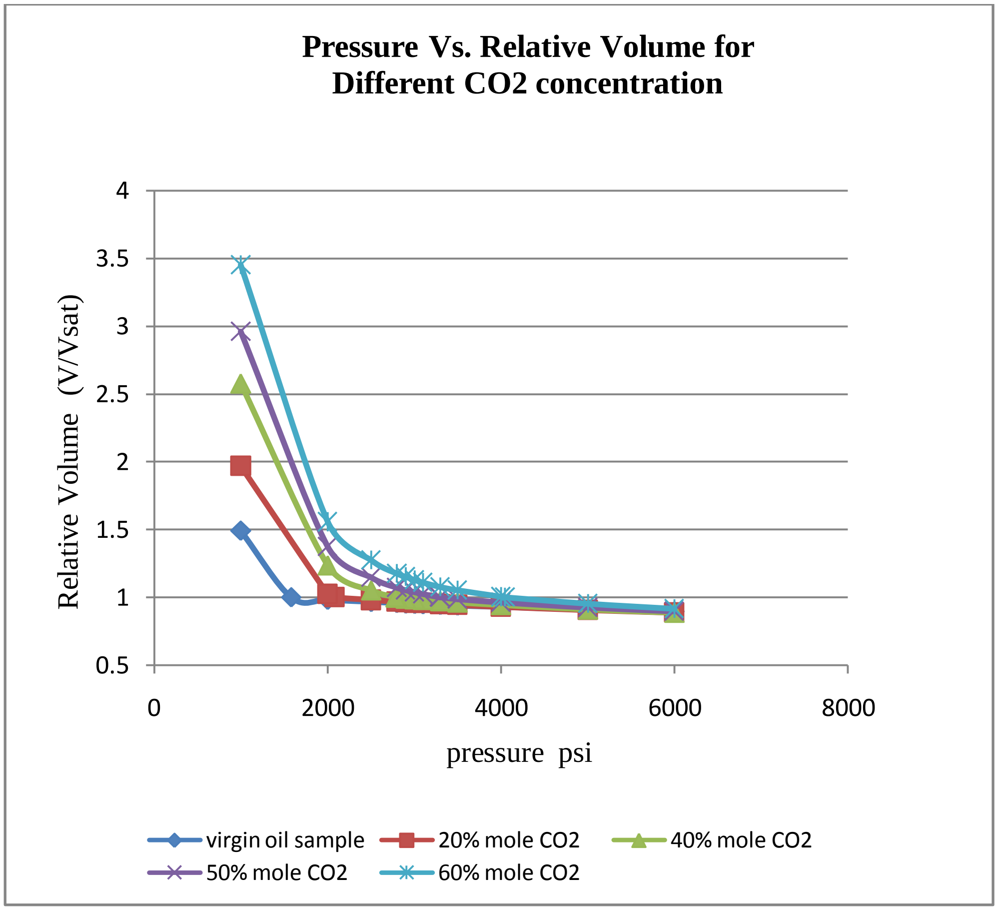
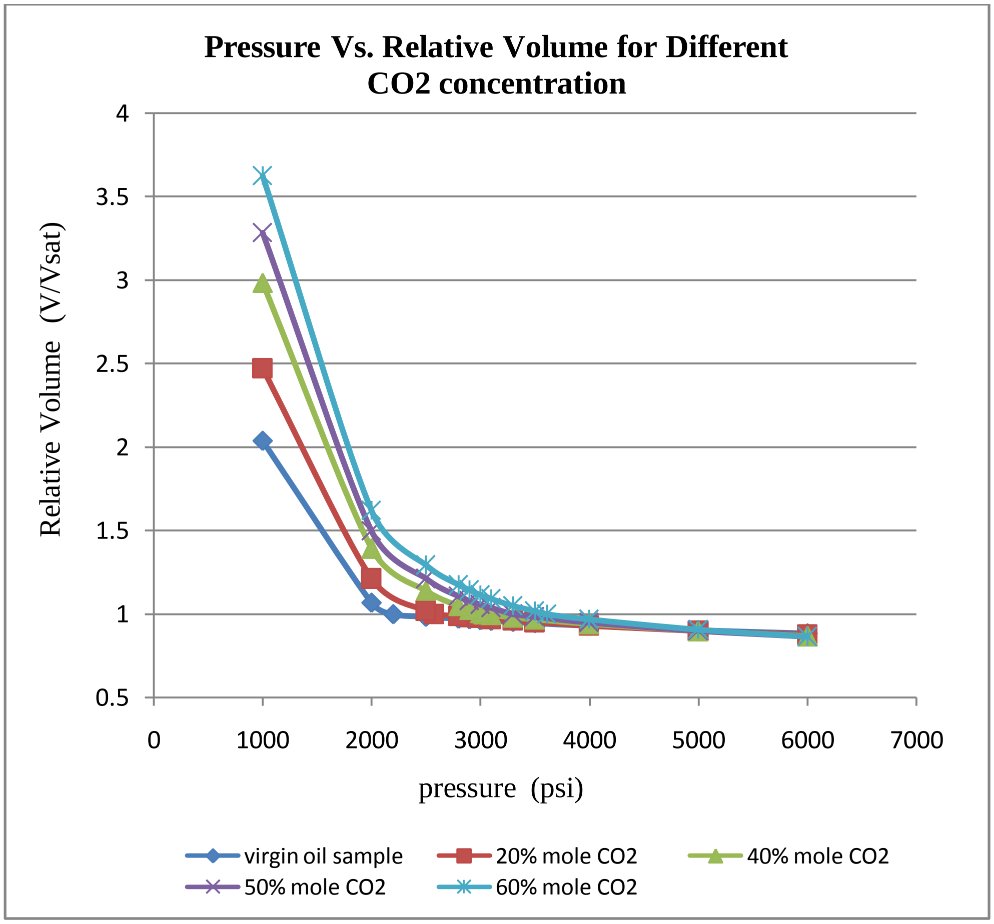
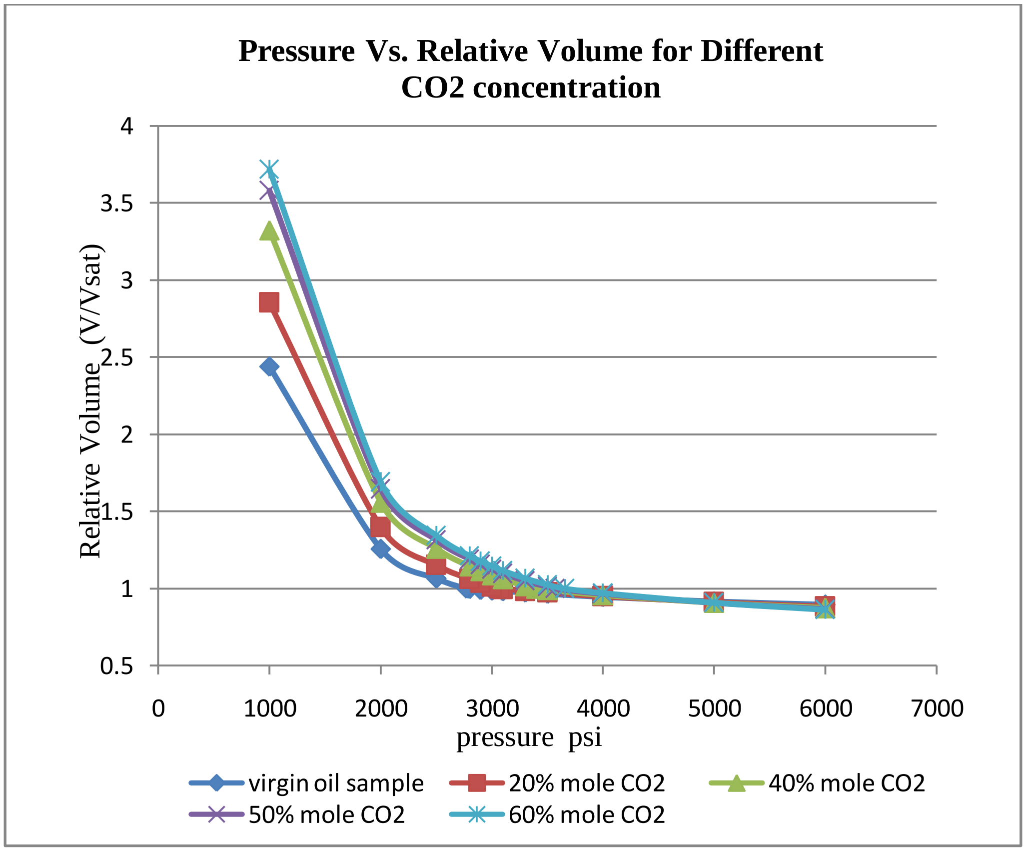


Figure – 8: Relationship between pressure and relative volume Oil sample No. 3



Relationship between pressure and relative volume
Oil sample No. 4



Relationship between pressure and relative volume
Oil sample No. 5

APPENDIX IV

SWELLING TEST RESULT

Swelling test result oil sample No. 1

CO_2 Mole %	Pb (psia)	S.F
0	1889.9	1
20	2313.96	1.076
40	2896.26	1.203
50	3379.52	1.3
60	4016.15	1.425

Swelling test result oil sample No. 2

CO_2 Mole %	Pb (psia)	S.F
0	2629.7	1
20	2975.18	1.101
40	3495.29	1.263
50	3927.81	1.385
60	4767.66	1.539

Swelling test result oil sample No. 3

CO_2 Mole %	Pb (psia)	S.F
0	1576.52	1
20	2078.77	1.117
40	2780.08	1.304
50	3294.08	1.441
60	4046.52	1.625

Swelling test result oil sample No. 4

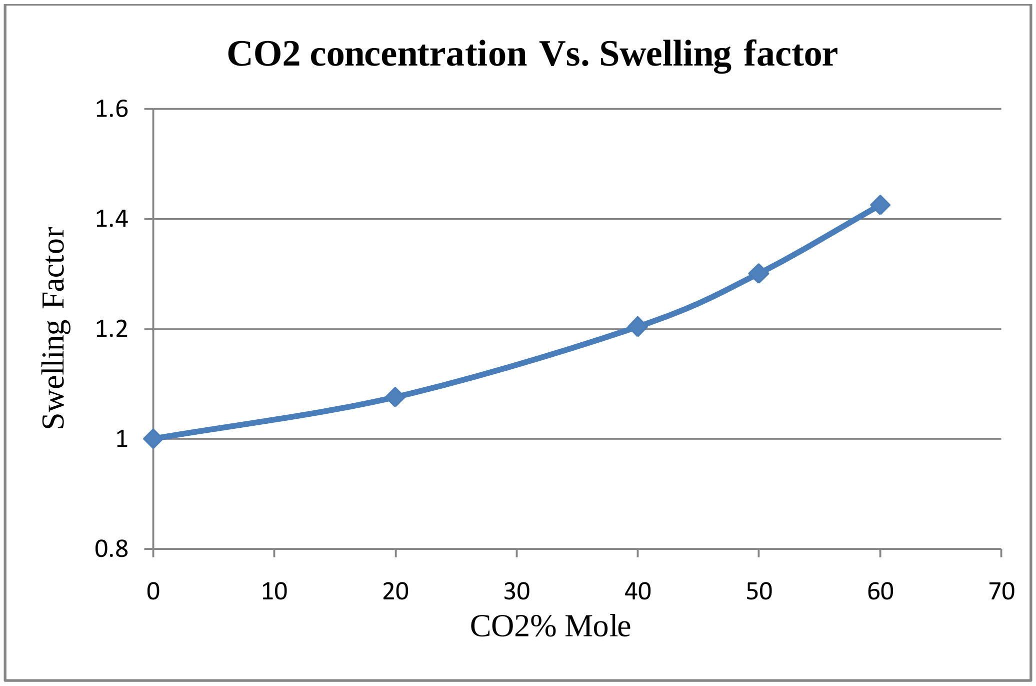
CO_2 Mole %	Pb (psia)	S.F
0	2197.36	1
20	2575.79	1.14
40	3027.77	1.37
50	3298.8	1.551
60	3611.23	1.816

Swelling test result oil sample No.5

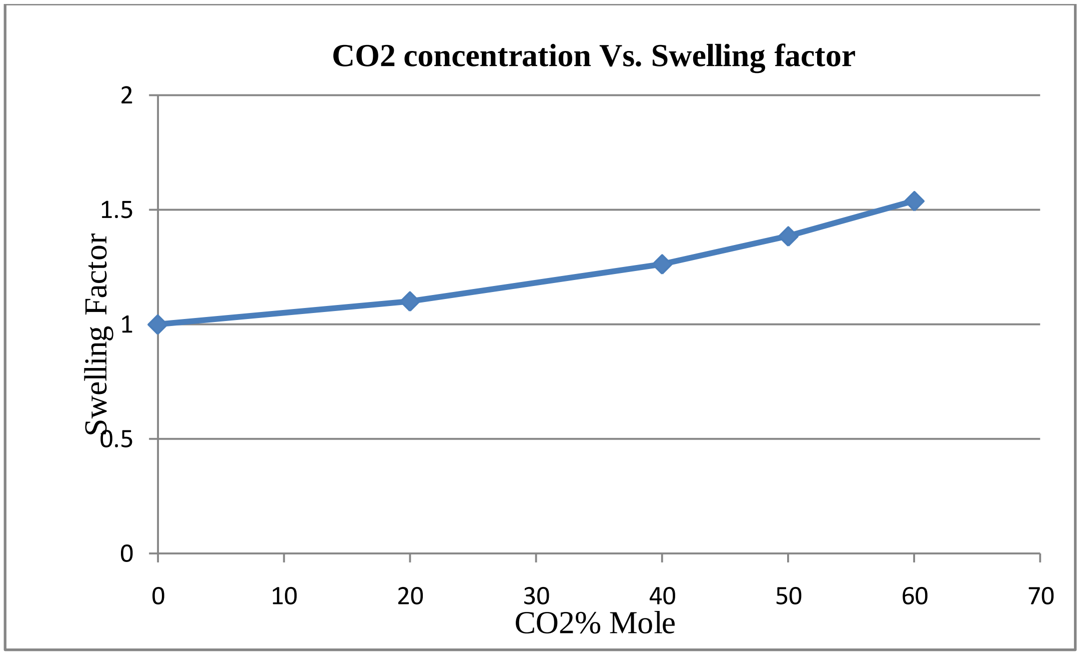
CO_2 Mole %	Pb (psia)	S.F
0	2771.9	1
20	3071.67	1.154
40	3397.38	1.413
50	3570.65	1.621
60	3658.81	1.759

APPENDIX V

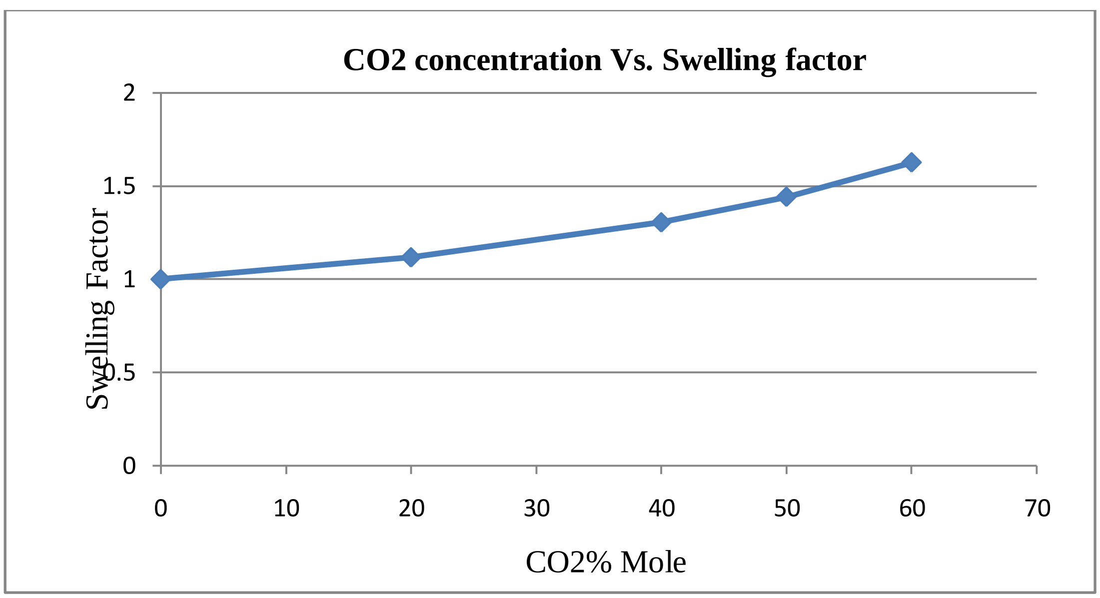
GRAPHS OF SWELLING FACTOR



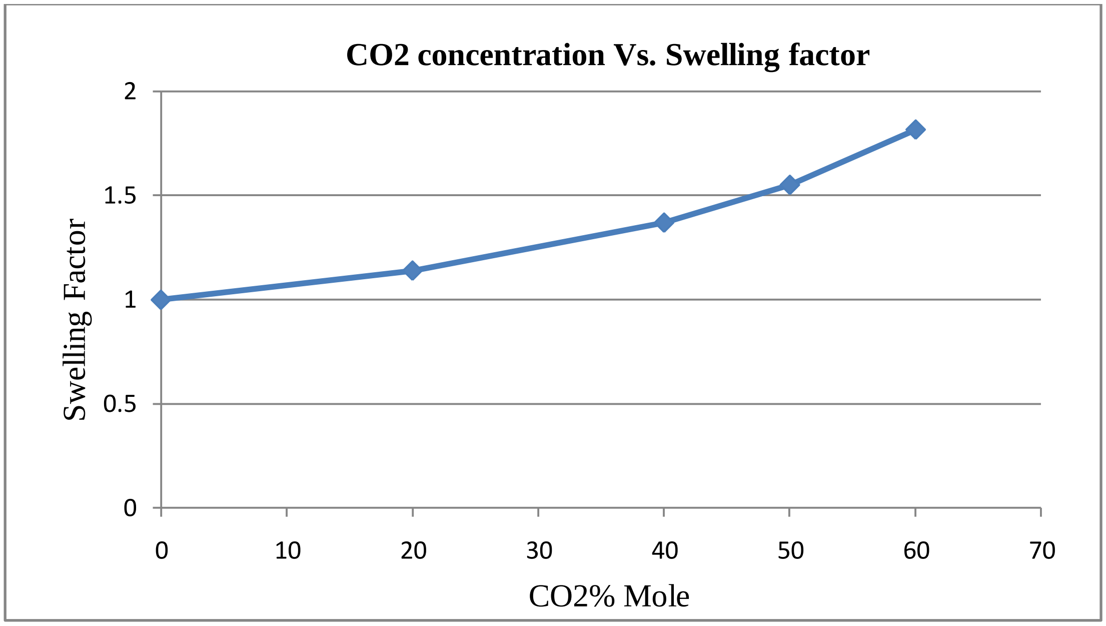
Relationship between CO_2 mole% and swelling factor
Oil sample No. 1



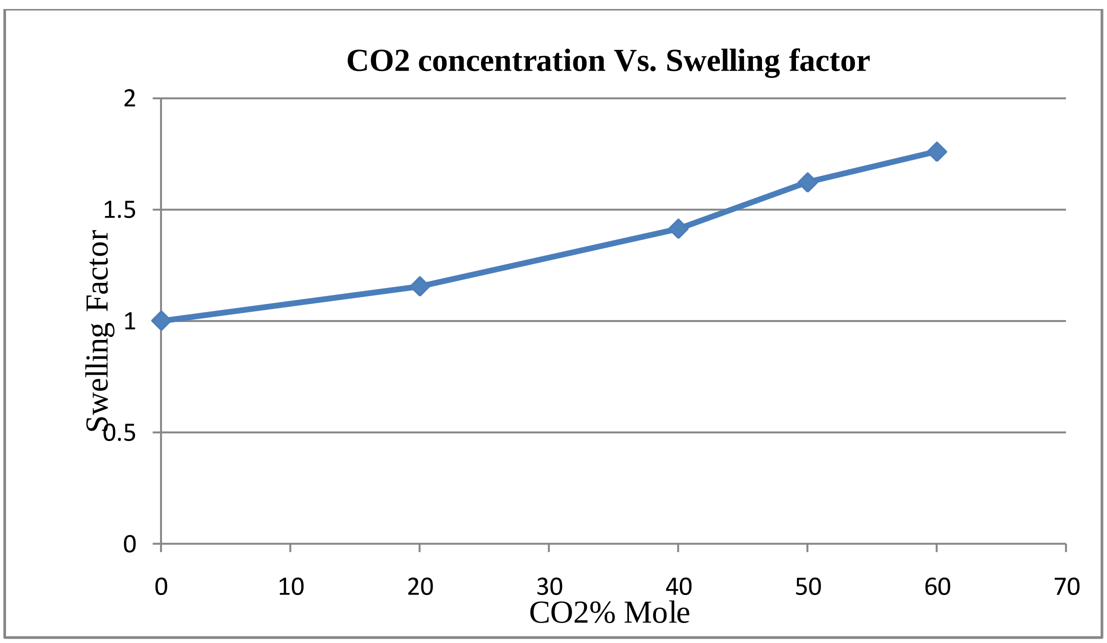
Relationship between CO_2 mole% and swelling factor
Oil sample No. 2



Relationship between CO_2 mole% and swelling factor
Oil sample No. 3



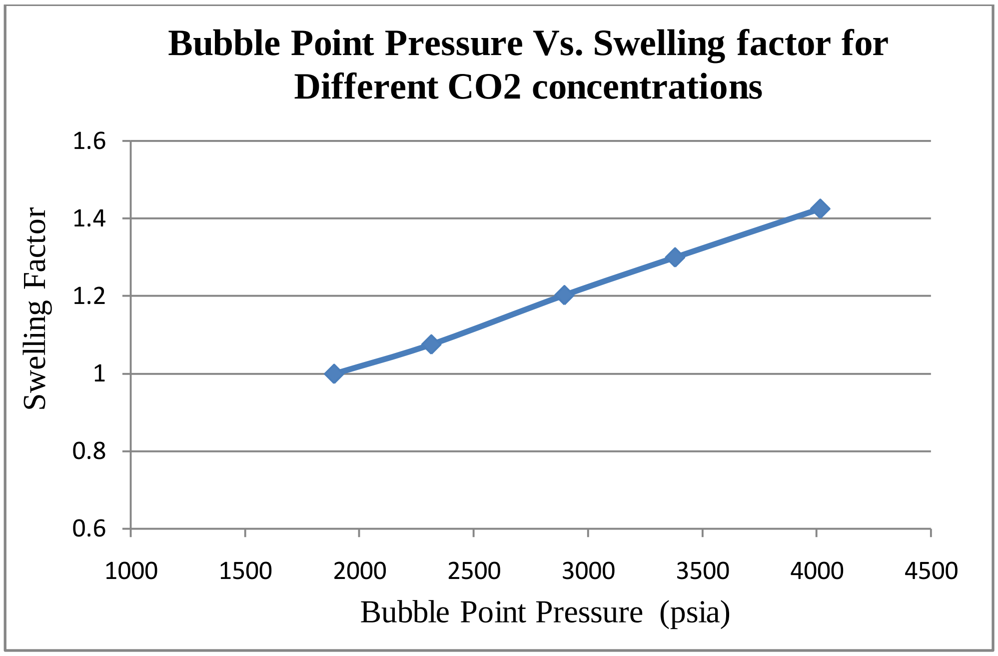
Relationship between CO_2 mole% and swelling factor
Oil sample No. 4



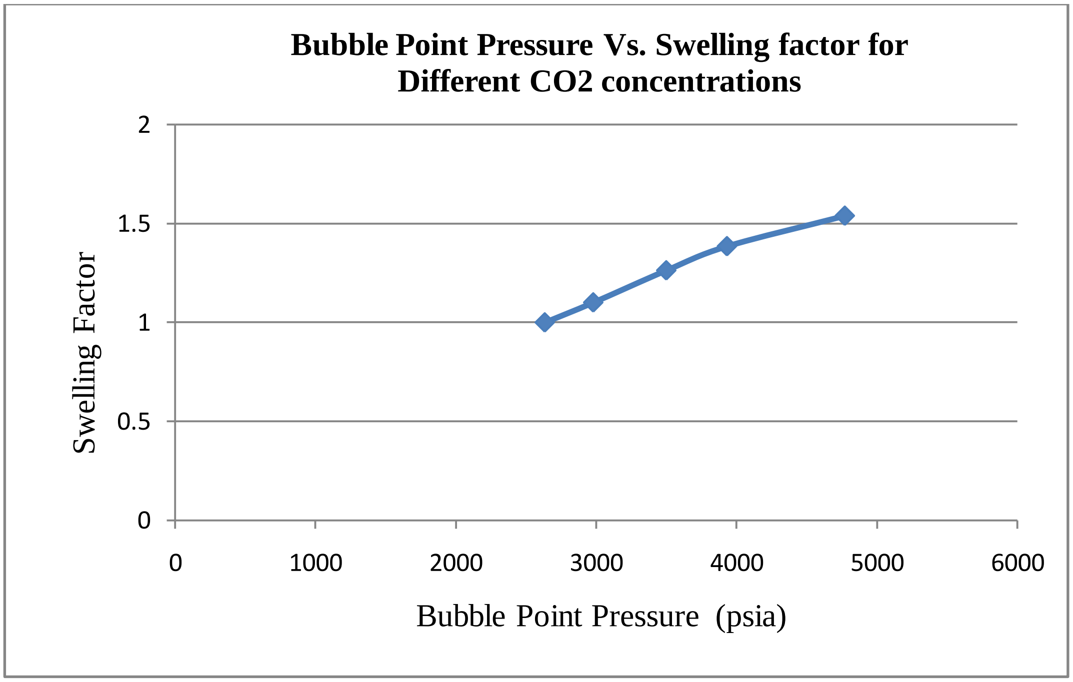
Relationship between CO_2 mole% and swelling factor
Oil sample No. 5

APPENDIX VI

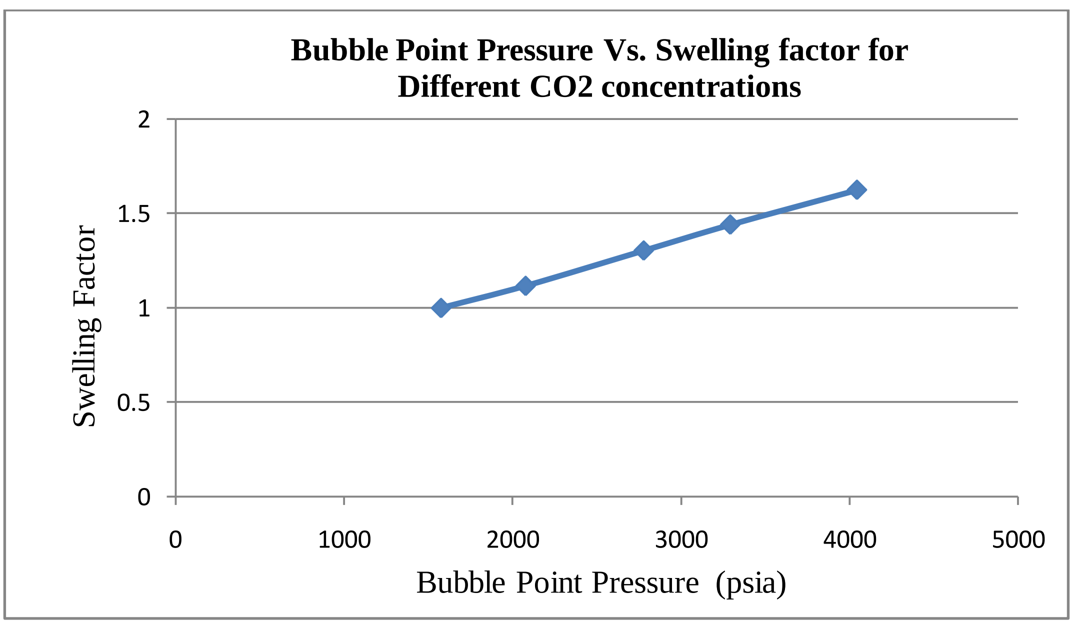
BUBBLE POINT PRESSURE VS SWELLING FACTOR GRAPHS



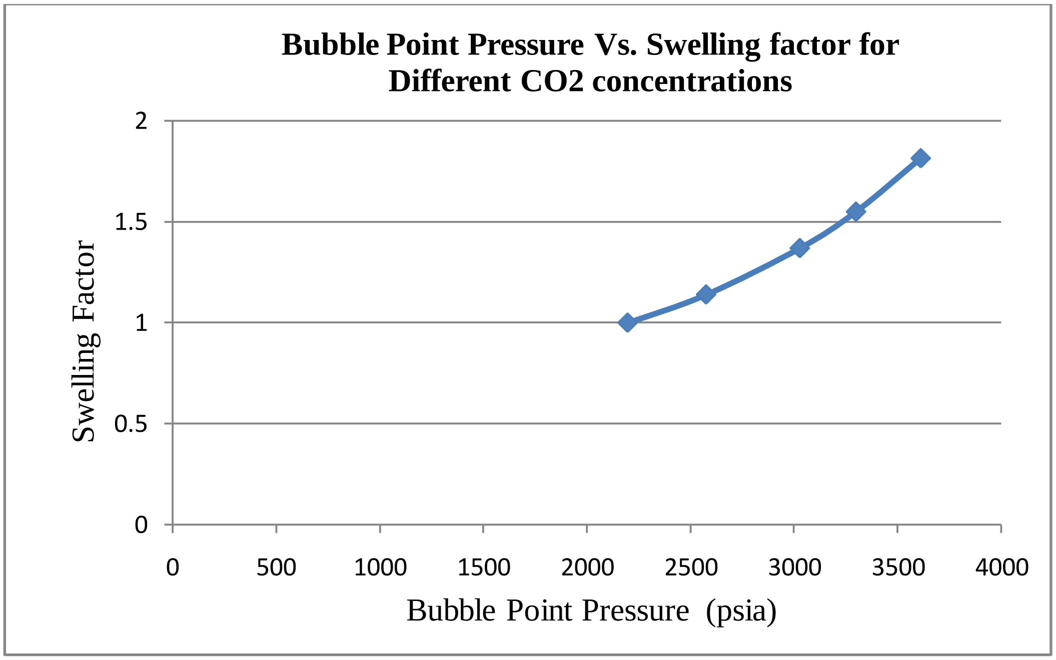
Relationship between bubble point pressure and swelling factor
Oil sample No. 1



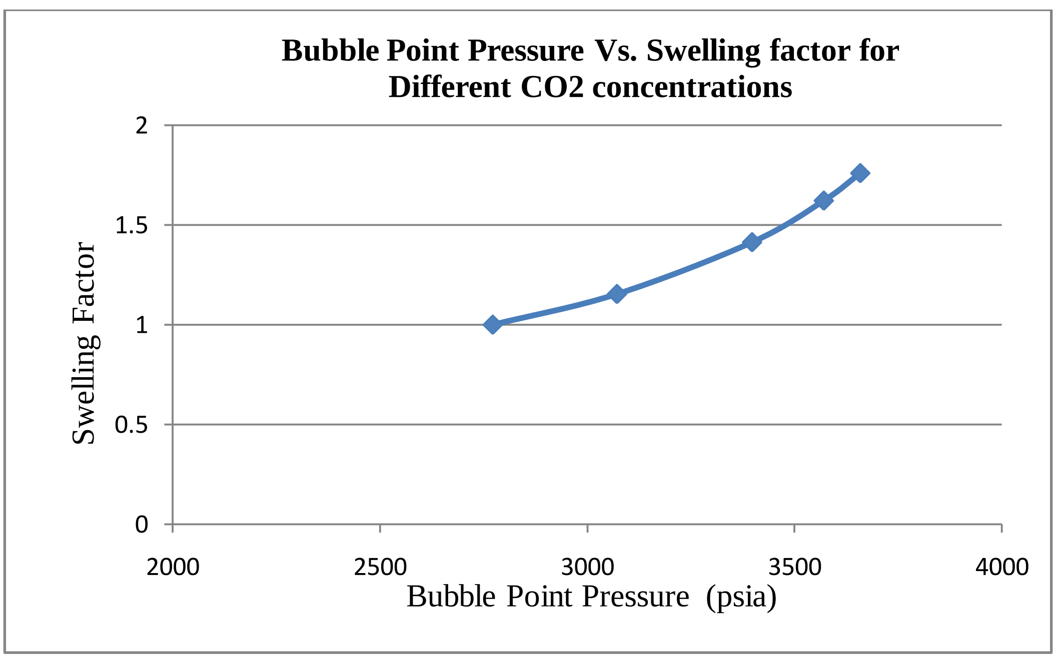
Relationship between bubble point pressure and swelling factor
Oil sample No. 2



Relationship between bubble point pressure and swelling factor
Oil sample No.3



Relationship between bubble point pressure and swelling factor
Oil sample No. 4



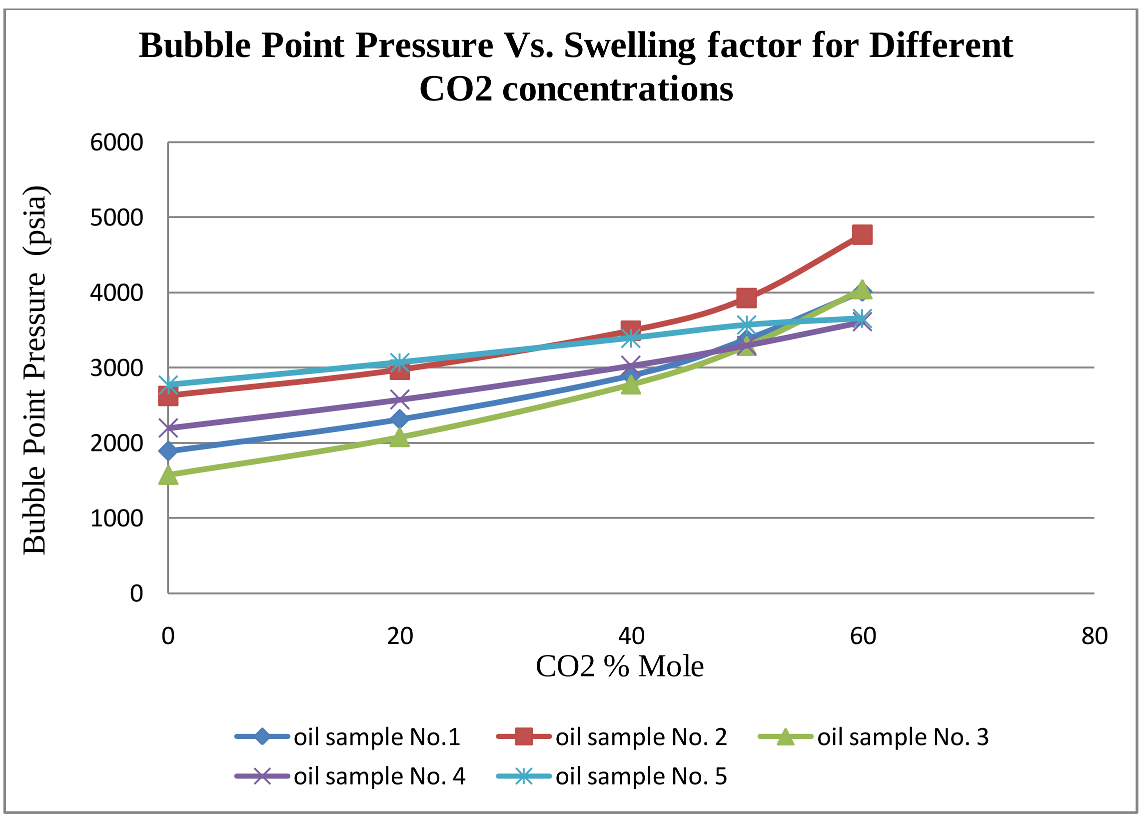
Relationship between bubble point pressure and swelling factor
Oil sample No. 5

APPENDIX VII

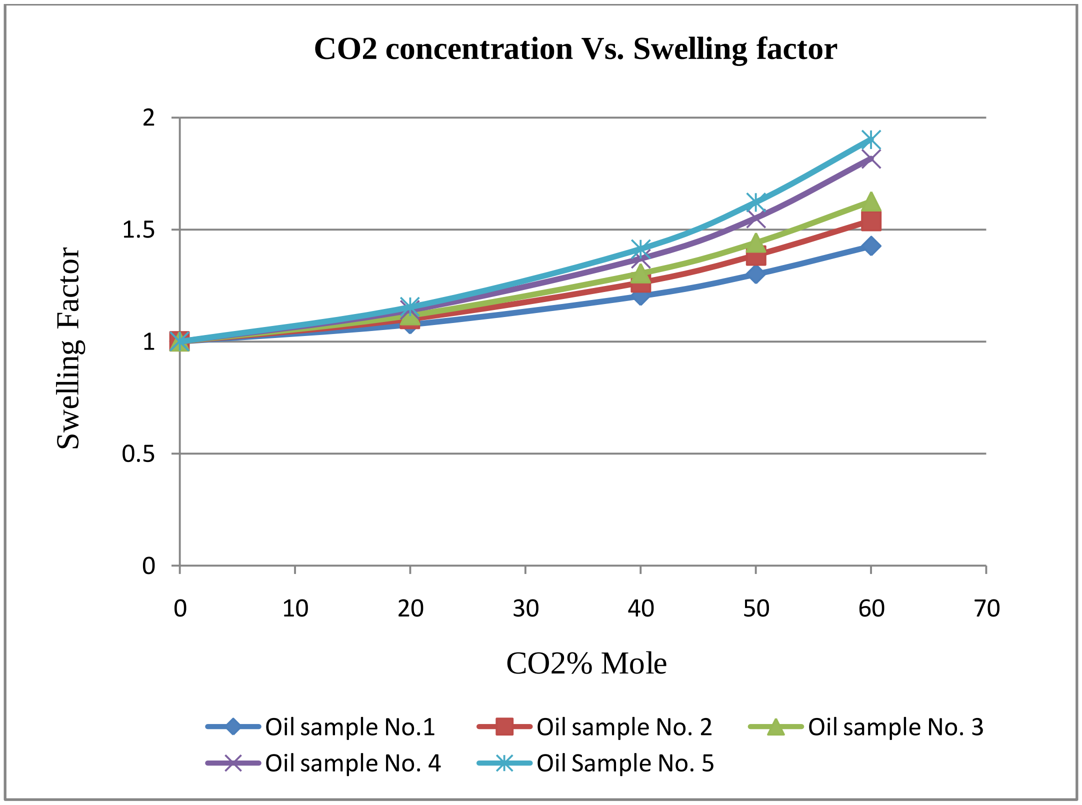
COMPARISON STUDY BETWEEN OIL SAMPLES

Summary of simulation result for 5 oil samples

Sample Name	Oil-1	Oil-2	Oil-3	Oil-4	Oil-5
API gravity	38	19	30	37	40
P_b (psia)	1889.9	2629.7	1576.52	2197.36	2771.9
S.F @ 20% mole CO_2	1.076	1.101	1.117	1.14	1.154
S.F @ 40% mole CO_2	1.203	1.263	1.304	1.37	1.413
S.F @ 50% mole CO_2	1.3	1.385	1.441	1.551	1.621
S.F @ 60% mole CO_2	1.425	1.539	1.625	1.816	1.759



Relationship between Bubble Point Pressure Vs. CO_2 % Mole
Five oil samples



Relationship between CO_2 concentration and swelling factor
Five oil samples